A THEORY OF GRAVITATION, HEAT AND ELECTRICITY

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— OF —

Gravitation, Heat and Electricity

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CHAPTER I.

ON THE NATURE OF THE GRAVITATING FORCE.

THERE are two principal forces of matter, one which draws or impells, the other tending to separate bodies. In the present treatise, that force which impells bodies is supposed to be seated in the interstellar medium; the separating force is inherent in the properties of the bodies themselves which are acted on. In order to explain them, we must have not only a theory of the properties of bodies on which they act, but we must have a theory, too, of the nature and constitution of the interstellar medium. It is a theory of this nature that I propose to develop in the following pages, beginning at chapter second. According to my view, gravity proceeds from the pressure of the interstellar medium, and is not the attraction of matter; heat and the other repulsive forces depend on the motions of molecules and atoms, but the particles of matter act not immediately upon one another, but through the interstellar medium. All this I will explain in the proper place, and will embrace in the same general theory an account of the phenomena of

gravity, affinity, heat, light, electricity and magnetism, and will show the relations of these forces to one another. But before proceeding with this, I will advance a few arguments to combat the common idea of attraction, and will devote the first chapter of this treatise mainly to that purpose. Some of these arguments are not new, but while the common idea of gravity prevails, a new theory of this force could not be properly introduced without them.

I am not sure that everyone will agree with me throughout as to the nature of force in general, though all of us, I think, must start together. Our first conceptions of force are derived from the inertia of bodies, either when we attempt to set them in motion, or when, being already in motion, we attempt to arrest them; in other words, it is that idea of force which is derived from mechanical action. But when we attain to more experience, and perceive that mechanical action may be produced by gravity, heat or electricity, and that these in turn, with exception of gravity, may be produced by mechanical action, we have come to apply the term force also to these agents. We find also that these forces are commeasurable, and that a definite amount of one is consumed or disappears in producing its equivalent of another. When this occurs, we do not say that one is annihilated, and that another to take its place is created, although, for all we know to the contrary, this may be the truth of the case; but we assume, upon the strength of a certain faith which we have in the immutableness of the Divine Nature, which is the true basis of the doctrine of conservation, that no creation and annihilation occurs, but that the forces are converted, and when mechanical action produces heat, it does not create heat, but becomes heat, and the motion of masses becomes the motion of particles.

The doctrine of the conservation and convertibility of forces has been established by experiment in reference to all

of the forces, which I have enumerated, except gravity, which alone has defied it, for while examples occur of its producing the other forces, none occurs in which it is produced by them, and instead of losing, as the others do, by production, it appears to gain in strength at the same time. But where these forces are convertible one into another, they must be all of the same nature. For, to convert dissimilar natures one into another, is an act of creation. It implies even more than this—a two-fold exertion of infinite power—both annihilation and creation. For who can conceive the conversion of matter into mind? or, rather, who does not perceive that it implies a contradiction? And why is this? It is because their natures widely differ. In like manner, no two things can be convertible without creation, it matters not how near their natures approach in kind, unless they be identical. Conversion can only apply to the different conditions and phases of the same thing. Consider, for example, the truly essential properties of matter, as extension, form, impenetrability, mobility and inertia. None of these properties are convertible. Their natures are entirely unlike, and their convertibility is impossible. But the forces of matter are concerned alone with the properties of its mobility and inertia. None of these properties can produce force, but force is rather a condition of these properties. Properties are unalterable. They can neither change nor be changed without creation, nor produce anything but themselves. Therefore, I propose to argue that the cause of gravity is not a property of the body that gravitates, but a force or condition, depending on a peculiar constitution of the interstellar medium. But first let me endeavor to illustrate what is meant by force, which is consumed or converted, and is capable of being measured. Let us, then, suppose a mass to be freely suspended in the air, and that we exert our strength against it and set it in motion. If we

now oppose the motion, which the body has thus acquired, we shall have to exert as much strength to stop it as we exerted at first to produce the motion. Now the question arises, whether the expenditure of our strength has imparted anything to the mass which it did not possess before? I answer: No, but the same space-appropriating power of the matter acts without increase or diminution, whether the body is at rest or in motion; but, in being changed from motion to rest, or from rest to motion, the direction of its action is changed. This change or conversion takes place within the suspended mass, and does not pass from one body of matter to another. It may be allowable, for convenience of expression and in conformity with usage, to say that force, meaning *momentum* or *resistance*, passes from one body to another in contact; but the expression should not lead us to regard *force* as a being or creation in the same sense as matter or mind. It is simply a condition. But it just as much requires a *cause* to change it. This cause, which changes the condition of motion or rest of one body, may be a condition of the opposite nature in another body. Thus in the case of a moving body, A, colliding with another body, B, at rest, the condition of the one is the force which is expended in producing a change in the condition of the other. The amount of dissimilarity of these two conditions is what constitutes the *intensity* of the force. The amount of momentum, depending on the amount of matter involved, constitutes the *strength* of the force. This is a simple illustration of force, which may be defined in general terms as a cause of a physical action, which is itself changed in producing change.

Now the question is, how we are to include gravity in this definition of force, since it appears not to be converted or consumed, like other forces, in producing change. Mayer, the eminent advocate of the doctrine of the conservation

and correlation of forces, attempted to relieve himself of the difficulty of this question by the assumption, that gravity—since it is not changed in producing change—is a property of matter, and not a force. But Faraday, carrying the conservation principle still farther, embraces gravity also in his idea of force; and because it is the cause of a physical action, inferred that the cause of gravity must be consumed, although the exact nature of the change has not yet been ascertained. "There is," says he, "one wonderful condition of matter, perhaps its only true indication, namely inertia; but in relation to the ordinary definition of gravity it only adds to the difficulty; for if we consider two particles of matter apart, attracting each other under the power of gravity and free to approach, they will approach, and when at only half the distance each will have stored up in it, because of its inertia, a certain amount of mechanical force. This must be due to the force exerted, and if the conservation principle be true, must have consumed an equivalent proportion of the cause of gravity."

Formerly there were considered to be many forces distinct and dissimilar in their nature, such as could produce change without being changed themselves. But now it is alleged that the effect is produced by conversion. When electricity produces heat, it is converted into heat; and when heat produces electricity, it is converted into electricity. But if recent investigations have demonstrated the conservation and the convertibility of all these causes of physical action, the opinion that these forces are dissimilar in nature can no longer be entertained; for to convert dissimilar natures one into another is as much an act of creation as to originate them. For, on what principle do we rely for the proof that heat is a mode of motion? Is it not the fact of the conversion of mechanical force into heat and the principle derived from reflection that *only things of the same nature*

are convertible? If this principle is not true, heat is not yet proved to be a mode of motion, but may be a repulsive property only of the opposite nature to attraction, and the particles of matter may repel as well as attract through a vacuum. Without this principle we cannot prove that heat is a force and not a fluid. But holding the principle to be true, we conclude that heat, into which mechanical force is converted, is the same nature under another form; that the motion of masses is converted into the motion of their particles; and that as masses rebound when they strike together, so the collision of the invisible particles of matter produce repulsion and the phenomena of heat. The same reason applies to electricity, to magnetism, and to gravity, which must therefore like heat be of the same nature as mechanical force, conditions of matter, and not properties of matter. It is true it has never been shown that any of these forces are converted into gravity, but gravity may be made to produce these forces; for gravity produces mechanical force and mechanical force may be converted, by impact or friction, into heat or electricity, while chemical affinity—which is attraction between the particles of matter—is the chief terrestrial source from which these forces are developed.

To show that the ordinary definition of gravity as a property of matter implies a departure from the principle of the conservation of force, we may take an illustration of this subject from the action of gravity upon the motions of the celestial bodies, by which action is apparently produced a creation and an annihilation of mechanical forces. The Earth, for example, moves in its elliptic orbit with more velocity at one season of the year than at another. Its motion is quickened as it approaches the Sun, and retarded as it recedes. Unless, then, its motion is in some way converted, it is lost. We cannot suppose that the Earth parts with motion into a vacuum, or that it receives motion

from a vacuum. If this were possible, there could be no reliable proof of the principle of conservation, which implies the inseparable nature of matter and force. It is true that we say the Earth's increasing velocity, as it approaches the Sun, is due to gravity; and that its loss of velocity, as it recedes, is also due to gravity. Is it possible, then, for us to conceive that the mechanical force is derived from a property when the Earth's orbital motion is accelerated, and that the mechanical force is annihilated by the property or reconverted into the property, when the Earth's velocity is diminished, a condition and a property convertible? From which reasoning it appears to me that the cause of gravity, like the causes of all other physical actions, must be a condition of matter and not a property. We must infer that gravity is due to a reaction of the same nature as that which awhile ago we supposed to take place between the moving body and the body at rest, the condition of one body producing a change in the condition of another. We cannot otherwise explain the force in harmony with the law of inertia and the principle of conservation. A body, to move itself, must alter its condition and create a new condition; to move another body, it must change the condition of this body. It is contrary to daily experience, where the cause and effect are such as to come under observation, that this change of condition ever occurs in the first case; nor does this disturbance of equilibrium ever happen in the second case except by reaction or conversion, when the two bodies are in contact. Upon this experience we found the doctrine of conservation and correlation of forces. Gravity alone appears to contradict the principle, and we can remove the difficulty, it seems to me, only by the supposition that gravity is caused by force or pressure operating through the interstellar medium. For then the Earth would part with its force or motion into this ethereal matter, when it moves

against the pressure of this matter, and would receive force or motion from it when moving in the same direction as the pressure.

Certainly, if matter be an involuntary agent, no change can take place in its condition without external cause, material or immaterial. How a material cause may operate in producing this change from rest to motion and from motion to rest in masses, whose motions come under immediate observation as in the case of the two colliding bodies above mentioned, is readily explained in harmony with well-established natural laws of matter. But the production of motion by a property or an immaterial agent, as the cause of gravity is sometimes assumed to be, since we cannot suppose that motion can be transferred from an immaterial in the same manner as from a material agent, is a different thing from convertibility, and implies creation and annihilation, as Faraday in the following passage clearly demonstrates: "The idea of gravity appears to me to ignore entirely the principle of the conservation of force, and by the terms of its definition, if taken in an absolute sense, 'varying inversely as the square of the distance,' to be in direct opposition to it; and it becomes my duty now to point out where this contradiction occurs, and to use it in illustration of the principle of conservation. Assume two particles of matter, A and B, in free space, and a force in each or in both by which they gravitate towards each other, the force being unalterable for an unchanging distance, but varying inversely as the square of the distance when the latter varies. Then at the distance of ten the force may be estimated as one, while at the distance of one—that is one-tenth of the former—the force will be one hundred. But from whence can this enormous increase of power come? If we say that it is the character of this force, and content ourselves with that as a sufficient answer, then it appears to me

we admit a creation of power, and that to an enormous amount; yet by a change of condition, so small and simple as to fail in leading the least instructed mind to think that it can be a sufficient cause, we should admit a result, which would equal the highest act our minds can appreciate of the working of infinite power upon matter; we should let loose the highest law in physical science which our faculties permit us to perceive, namely: *the conservation of force.* Suppose the two particles A and B removed back to the greater distance of ten, then the force of attraction would be only a hundredth part of that they previously possessed. This, according to the statement that the force varies inversely as the square of the distance, would double the strangeness of the above results; it would be an annihilation of force, an effect equal in its infinity and its consequences with creation, and only within the power of him who has created."

"The usual idea of the force," says Faraday in another passage of gravity, "implies direct action at a distance. And such a view appears to present little difficulty, except to Newton and a few, including myself, who in that respect may be of like mind with him. Some are much surprised that I should, as they think, venture to oppose the conclusions of Newton; but here there is a mistake. I do not oppose Newton on any point; it is rather those who sustain the idea of action at a distance that contradict him. Doubtful as I ought to be of myself, I am certainly very glad to feel that my convictions are in accordance with his conclusions; at the same time, those who occupy themselves with such matters ought not to depend altogether upon authority, but should find reason within themselves, after careful thought and consideration, to use and abide by their own judgment." The opinion of Newton to which Faraday here alludes is found in the following extract: "That gravity,"

says Newton, "should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial I have left to the consideration of my reader." Euler after Newton, and Descartes before him, reasoned of gravity in the same strain. Kepler accounted for the tides by the attraction of the Moon. But Descartes rejected this hypothesis; "For to conceive this," says Descartes, "we must not only suppose that every portion of matter in the Universe is annimated and annimated by different souls which do not obstruct one another, but that these souls are intelligent and even divine, that they may know what is going on in the most remote places without any messenger to give them notice, and that they may exert their powers there." The law of gravitation none disputed. It was plain, therefore, that bodies are either attracted or impelled according to this law. A number of hypothesis therefore have been proposed, based on the principle of impulsion by the interstellar medium. One of these by Descartes, based on the hypothesis of two ethers, was intended to explain the circular motions of the heavenly bodies; another by Newton based on the hypothesis of a single fluid of varying density, and a third by Le Sage, were intended to account for the tendency of bodies to approach one another on the theory of impulsion. The anxiety of these philosophers to find a better explanation of gravity than what is generally received, and the favor with which their attempts have been viewed by other kindred spirits, are proofs of the difficulties

which have been always experienced by those who think upon this subject in reconciling the properties of attraction and inertia.

Before the law of universal gravitation was fully expounded, the upward motion of flame was thought to proceed from a principle of levity. So now it may be that our ignorance as to the nature of the reaction of the interstellar medium upon bodies may lead us to attribute the fall of bodies to a principle of attraction. It is the reaction of the atmosphere upon the heated gas of the flame that causes it to ascend; and why may not a similar reaction of the interstellar medium upon bodies produce changes in their positions? It might be answered to this that such a hypothesis demands too great a result from the action of a fluid so rare and subtile as the luminiferous ether. We move so easily through space and observe the motions of the heavenly bodies so unchanging and unobstructed, that both our bodily feelings and our mental deductions might incline us to the doctrine of a vacuum. But this objection may proceed altogether from an illusion. For we know that the atmosphere exerts a pressure of fifteen pounds on every square inch of surface, and that notwithstanding this great pressure we move freely and without sensible impediment from this circumambient fluid. This freedom we attribute to its elasticity. The same argument applies to the luminiferous ether. It matters not how great its density or pressure, if its elasticity is correspondingly great so as to overcome the inertia of its particles, it would present no impediment or obstruction to the motion of the heavenly bodies, nor would we be sensible of its presence. Moreover, this objection, which might be raised against an impulsion theory of gravitation, applies equally to the undulatory theory of light and heat, as any one may observe who examines this question. For accepting the undulatory

theory of light as an established principle, the pressure or "bursting power" of the luminiferous ether, according to the estimate of Sir John Herschel, must be about seventeen trillion pounds to the square inch, estimating that of the atmosphere as fifteen. "Do what we will," says he, "adopt what hypothesis we please, there is no escape, in dealing with the phenomena of light, from these gigantic numbers, or from the conception of enormous physical force in perpetual exertion at every point through all the immensity of space." Now, the atmosphere surrounding bodies in contact is capable of holding them together by its pressure with the force, which I have already mentioned. When we read, then, the immense numbers expressing the bursting or compressive power of the luminiferous ether, need we look elsewhere for a force by which the particles of matter are held in cohesion whenever they come in contact? We rather wonder by what force atoms in contact escape again from this gigantic embrace!

How this ether produces attraction between bodies not in contact, is a question, which involves a theory of its constitution. The supposition of the existence of such a fluid, which Huyghens introduced as the basis of his undulatory theory of light, and which Newton suggested might produce by impulsion the gravitating force, was previously proposed by Descartes as well to explain the properties of light as to account for the motions of the planets around the Sun. Newton and Huyghens conceived the ether as a single fluid, whereas Descartes asserted there were two. Subsequently the hypothesis of two fluids was independently proposed by Du Fay to explain the phenomena of vitreous and resinous electricity, but again fell into disfavor when Franklin suggested that the phenomena were explainable on the hypothesis of a single fluid, and substituted the terms *positive* and *negative*. By a course of reasoning entirely independent, I

have come to the same conclusion with Descartes and Du Fay. But in the use to be made of the hypothesis, I shall exceed the limits to which it has been hitherto carried. For whereas it has been proposed with a view only to a single result, that of generalizing facts either under the head of heat, or light, or electricity, or gravity, I hope to carry the generalization a step farther, and to show that the scope of a Double Ether Hypothesis, which it is the object of this treatise to revive for a third time, is wide enough to embrace in one theory an explanation of gravity, heat and electricity in conformity with the doctrine of conservation and convertibility of forces. Descartes, says Hallam, was driven to this hypothesis of a double ether by his aversion to admit any vacuum in nature. His reason may appear somewhat obscure to us, but is certainly entitled to our respect, not simply out of consideration for the genius of its author, but from the fact that from the same idea of the immutability and divine perfection of the Creator, Descartes deduced another important principle, that there must always be the same amount of motion in the universe, and that no motion can be lost, which I understand to be the same thing, as is referred to in modern philosophy as the conservation of force. But whether his reason be received or not, it is certainly just as easy to suppose two fluids as one, or to suppose even three or more, if necessary to explain natural phenomena. For it is not supposed that they occupy the same space, but that one pervades the pores of the other. The atmosphere itself is not a single fluid, but composed of many; and what is more remarkable, each one of the gases or vapors which compose it exerts its own separate, individual pressure. In like manner, I suppose that space is filled with two ethers, and that each exerts its own separate pressure.

The suppositon that ether is endowed with an expansive

elastic property seems to require one of two hypothesis: either, as Sir John Herschel says, that the universe may be surrounded with a hard or crystalline shell capable of confining and resisting the outward pressure of the ether, and preventing its expansion; or else that there is a continual production of new ether at the centre of the universe, so as to fill the vacuum caused by its expansion. It seems to be a law of nature that nothing is wasted. The old and effete matter of worn out worlds becoming useless, when it has reached the centre of the universe, may be there converted by the Almighty into imponderable matter, and this may by the law of its nature have an outward tendency, just as all ponderable matter has a tendency inwards. On the other hand, the ether, when by expansion it has reached the confines of our universe, must become useless as ether, and may be there converted into ponderable matter, and precipitated back into the universe again on an inward mission of Providence. This work may not necessarily be regarded as a creation of something new, but a separation and combining again of the primary elements of matter. These speculations, which are the legitimate fruit of the hypothesis of an elastic medium, are beyond the province of demonstration or proof, but appertain to the undulatory theory of light—which is now commonly received—no less than to an impulsion theory of gravity.

CHAPTER II.

THE FORCES OF GRAVITATION, COHESION AND CHEMICAL ATTRACTION ARE DUE TO A PECULIAR STATE OF THE INTERSTELLAR MEDIUM, WHICH IS COMPOSED OF TWO ETHERS OF UNEQUAL ELASTICITY, ONE OF WHICH PERVADES AND HAS THE POWER OF COMPRESSING THE OTHER.

THE processes of Nature are connected by a series of analogies, by means of which we not only trace a unity of design and workmanship in the whole, but ascend step by step to a more thorough knowledge of the physical world. The modern theories of sound and light and heat are derived from these anologies, and it is upon the strength of conviction which they are calculated to enforce, that I have been encouraged to undertake a theory of gravity, in which the principle of impulsion is substituted for that of attraction at a distance. All the other forces of matter have been explained in accordance with the doctrine of conservation. This must be explained in harmony with the same principle, if it is analogous to the rest. Experience rejects the idea that matter can act, where it is not or has no channel of communication. We could not be satisfied that sound could pass from a distant object to us, unless matter were the channel through which, or by means of which, it is conveyed. Either then it was an emanation from the sounding body, which was readily confuted, or it was an undulatory motion through the atmosphere like that which is seen on the surface of water, when its molecules are subjected to a sudden displacement. Secondly, light, for the same reason as sound, required a medium, and this medium, like that of sound, must be a material medium; it must consist of par-

ticles emitted from the luminous body; or it passes like sound, by the undulation of an elastic fluid. The air was found to be too coarse a substance for the enormous velocity of light, and *ether* was invented; hence arose the undulatory theory of light.

Reasoning from the very same principles, men have tried to explain gravity, which requires, as well as sound or light, the existence of some medium between the distant objects between which it acts. The very same agent which produces light has been suspected, but the mode of its action has not been explained. The nearest approach to an explanation is the hypothesis of Sir Isaac Newton, "that all bodies are surrounded by an elastic fluid, which increases in density outwardly from the bodies which it surrounds; and that gravitation is the tendency of bodies to pass from the denser parts of this fluid to those parts where it is rarer; and that in this way bodies are impelled to one another." This hypothesis labors under one difficulty, that of explaining how the elastic fluid is kept in such a condition of varying density as here supposed. It is for the removal of this difficulty, and not for the substitution of a new theory, that I have invented the hypothesis of a second fluid, less elastic than the ether, and pervaded by it. The theory itself, like the undulatory theory of light, is supported by an analogy to the action of air; and as the one may be derived from a knowledge of the air's motions, so the other from its pressure.

It is said that air exerts a pressure of fifteen pounds to the square inch on all bodies at the surface of the Earth. If, therefore, the surfaces of two bodies be brought in contact, the pressure of the atmosphere on their farther sides will cause a cohesion between the bodies, which will require a force, for every square inch of surface in contact, equal to raising fifteen pounds to separate them. Here, then, is a

species of cohesion produced between common or sensible matter by the pressure of an elastic fluid, the air, surrounding the Earth. The force which holds the two masses together is in the atmosphere, and is not a property of the masses. Likewise, the force which is employed to separate them is exerted against the body of the atmosphere and not against the masses. We see similar effects between the minute particles of matter; but we know that the air is not of sufficient tenuity to pervade the pores of bodies, and to produce these effects upon their minute particles; and besides this the molecular forces are much more intense than the pressure which is produced by the atmosphere. Hence, in order to account for the cohesion between atoms and molecules of matter, we have to suppose the existence of a fluid more subtile than the air, and at the same time more elastic. The investigation of the phenomena of light has proved the existence of such a fluid; but this does not afford us a full or an exact explanation of cohesion or gravity. For that bodies which gravitate are not in contact like those bodies which the air holds together by its pressure is evident to all, and we know too from closer study that atoms and molecules are not in contact; and, moreover, I shall attempt in the course of this theory to prove that they never come into contact. What we have said, however, may be regarded as a coarse illustration of the manner in which a fluid may produce by pressure a certain kind of attraction; and the analogy of this action of the atmosphere to the action of cohesion between the particles of matter—taken together with the proof from light of the existence of the ether, with its all-pervading and elastic properties—is strong enough to encourage us to base much upon it, and to pursue the resemblance as far as any exists. The elastic force of the atmosphere at the surface of the Earth is due in great part to its gravity; and the elastic force of the medium, which we

suppose to act upon the minute particles, must likewise be due to some sort of compressive force. But how the Almighty effects this compression it is needless to inquire, as it is impossible to determine: it is enough for our purpose that, if there be any interstellar medium or ether, as commonly supposed, of that nature which is described in the undulatory theory of light and radiant heat, the known properties of matter lead us to conclude, that, without heat, it would produce some sort of cohesion, in the same manner as air, between loose particles of matter in contact. By loose particles I mean such as have no forces of repulsion or attraction acting upon them. Let us then follow out this idea of impulsion suggested by the pressure of the air.

The luminiferous ether is commonly represented as a single fluid, and so far we have only considered it as such. But two philosophers, Descartes, in his account of light and gravitation, and Du Fay, in his theory of resinous and vitreous electricity, have presented the idea of two fluids. I have already suggested my reason for adopting a hypothesis of a double ether, and I will now proceed to point out more fully what I conceive to be its nature, and the relations of the two fluids composing it. Some idea of this may be gotten from the following extract from the writings of Descartes; but I will give the two fluids names, and for the purpose of distinction will call the more rarefied *ether*, and the other *caloric*: "I will tell you," says Descartes, in a letter addressed to a friend, "that I can conceive, or rather can demonstrate, that besides the matter which composes terrestrial bodies, there are two other kinds, one very subtile, of which the parts are round like grains of sand, and this not only occupies the pores of terrestrial bodies, but constitutes the substance of all the heavens; the other incomparably more subtile, the parts of which are so small and move with such velocity that they have no determinate figure, but

readily take at every instant that which is requisite to fill all the little intervals which the other does not occupy."

The *ether* and *caloric*, for so we have named the two fluids, either separate or combined, pervading all other matter, might produce, in the absence of heat, that sort of cohesion between molecules which we have already pointed out. In the same manner we may suppose that ether pervading the pores of caloric with the utmost freedom, would produce cohesion between its atoms when brought in contact, provided the pressure of the ether were sufficiently great to arrest the motion of the caloric particles. It is plain that the pressure of the *ether* would in this way diminish the elasticity of the *caloric*, and that the caloric, therefore, would be a less elastic fluid than the ether. For while the ether would diminish the elasticity of the caloric, the caloric could have no such corresponding effect upon the elasticity of ether, for here the analogy is perfect between the pressure of the ether upon the caloric particles and the pressure of the atmosphere upon bodies, which it may be made to hold in contact. As the air is not affected in its elasticity or expansive force by the presence of these bodies, neither would the ether be affected or lessened in its elasticity by the presence of the caloric particles. The expansive force or elasticity of caloric, therefore, cannot be infinite, and as compared with ether, there may be considered to exist a slight cohesion between its particles.

I have now given a reason for the supposed difference of these two fluids in respect to elasticity, namely, the reaction of one on the other. I am now to explain how that pressure, which can produce the cohesion of bodies in contact, may be so modified as to produce the approach of bodies not in contact; the force of gravity being the residue of that pressure which the ether exerts in compressing the caloric. We have supposed all space to be filled with at least three species of

matter. First, at the center of the universe is a solid mass of what, under the influence of ether and caloric, is ponderable matter, composed of atoms comparatively speaking very large. Second, above this and around it is an atmosphere of caloric, varying and decreasing in density as it extends outwardly, and composed of atoms very much smaller than the first. Third is the ether, which fills the pores of the two other species of matter. It increases in density as the caloric diminishes, the two fluids being thus oppositely arranged and together filling space. The ether's condition is therefore like that of the fluid in the hypothesis of Sir Isaac Newton, in which he suggests that there is an elastic medium pervading all space and increasing in density as we proceed from dense bodies outwards, that this "causes the gravity of such dense bodies to each other, every body endeavoring to go from the denser parts of the medium to the rarer."

It is plain that the condition of the ether, since it freely occupies all space, is due to the presence within it of the two other species of matter. But we suppose the main cause of the varying density of the caloric to be the circumambient and pervading ether, acting by pressure both upon the circumference of the caloric from without, and also inwardly upon the caloric atoms, and retarding their expansion. (But it might be that the caloric reacting upon itself in expanding would produce the same result.) We are to consider that the ether exists not only within the caloric, but that it extends much beyond it, and environs it just as the caloric environs the dense body at the center of the universe. It presses not only upon the caloric atoms within, but inwardly upon the caloric mass from without. Thus the ether's pressure may be said to be to the caloric what gravity is to the Earth's atmosphere and gives it the same form. It diminishes the elasticity or expansive force of the caloric

not only by pervading its pores and retarding the repulsion of its atoms whenever they collide, but it presses inwardly upon the circumference of the caloric globe (for the compression of the ether would give it this shape), and sends its pressure by transmission through the caloric medium in the direction of the centre, just as the lower parts of the Earth's atmosphere press upon the Earth's surface, not only with their own gravity, but sustaining that of the parts above. The ether does not compress the caloric as the atmosphere compresses water, by a pressure which is wholly external, nor does it diffuse itself freely through the caloric, as gases are diffused. But its action is of a kind intermediate between these: it pervades and compresses at the same time. For in the diffusion of gases, as well as in the mixture of liquids, there is some attraction between the heterogeneous molecules, or, at any rate, less repulsion than there is between molecules of the same kind. This aids the diffusion. But in the case of ether and caloric, no relation of this sort subsists. We cannot infer from the above considerations that the same stability exists in the density of the caloric as apparently exists in the atmosphere of the Earth. They rather imply, as far as we can see, that the density of the caloric is always diminishing, and that the caloric globe is forever expanding. But since the perception of natural changes always grows less with the increase in magnitude of the masses in which any change occurs, whether we suppose the ether to exercise a pressure upon the caloric globe capable of controlling its dimensions, or whether we suppose that it goes on eternally expanding and enlarging, the effect is the same so far as the phenomena of gravity are concerned, provided the ether and caloric have that varying density explained in this hypothesis.

We have now proceeded so far in explanation of gravity as to have assigned a cause for that condition of ether repre-

sented in the hypothesis of Sir Isaac Newton; but, at the same time, we have introduced another medium throughout space in the opposite condition, and it might at first view be supposed that the pressure of one fluid would counteract that of the other, and that, if, as Sir Isaac Newton supposed, the ether in the condition represented would produce impulsion, the caloric, in the reverse condition, would produce repulsion to an equal amount. This would obviously be the case if the two fluids possessed the same elasticity, and the caloric pressed from the center with the same expansive force with which ether presses to the center; but this is contrary to the hypothesis, and I have supposed the force of gravitation to be the ether's excess of expansive force.

In their relations as distinct media, the ether will be found as represented in the hypothesis of Sir Isaac Newton, and will increase in density from the center of the universe outwards; the caloric, on the other hand, will be represented by a globe of fluid having its center at the universe and increasing in density as its center is approached, and partaking in its nature of solidity, inasmuch as there is a cohesion between its particles produced by the pressure of the ether. It is only relatively, however, and on account of its having less elasticity than ether, which alone is a perfect fluid, whose particles have no sort of attraction either for themselves or any other species of matter, that caloric can be compared in any respect to a solid; for, as I have regarded it as the medium of radiation, it must be very elastic, and presents also but little obstruction to the motions of the heavenly bodies. And yet, in the relations of ether and caloric, we may reason upon one of them as a fluid and the other as a solid, because the elasticity of one is greater than that of the other and because one has cohesion and the other not. By taking this comparative view of ether and caloric, *gravitation* may be described as a form of cohesion, and as

this appears to be the easiest way of presenting the subject, I will adopt this plan first.

We have explained that cohesion between the particles of matter may be effected by the pressure of ether. We supposed these particles to be solid. But we have thought it allowable, also, to view the caloric relatively as a solid body on account of the superior fluidity or elasticity of the ether. We may thus conceive two globes of caloric as solid bodies, held in cohesion by the pressure of the ether or mashed and compressed together, or we may conceive of a solid body held in cohesion with a globe of caloric. For, by the compressive force of the ether, the caloric is rendered somewhat in the nature of a solid mass, its particles having the property of cohesion in a slight degree, and its nature approximates more and more to that of a solid as we move in the direction of its increasing density or towards the center. Therefore, in whatever part of the caloric any dense body is placed, the caloric mass conceived as a solid, to which the dense body may cohere or be pressed by the ether, would be on that side of the body which is next to the center of the caloric mass, which, in the present consideration of the subject, is the center of the universe. Therefore, the dense body being pressed as in cohesion to the caloric globe, would continually move towards its center; for the caloric mass may be contemplated as a solid body, whose circumference is continually giving way at the point of contact with the gravitating body, and yet continually presenting a new surface on that side of the dense body which is next to the center of the caloric globe.

We illustrated the cohesion of atoms produced by the impulsion of ether by that species of cohesion which may be effected between two bodies by the pressure of the atmosphere. This sort of cohesion takes place not only between solid bodies, but occurs also between liquids. The different

degrees of cohesion between the particles of water, which boils at a lower temperature on the mountain summit than at the level of the sea, are due to this cause—so that it is not necessary that the bodies between which this sort of cohesion is produced should be solid. Indeed, there is no such thing as a perfect solid in nature, except the simple atoms, of which all bodies are composed. All other bodies which are masses of atoms are only relatively solid, according as they are more or less pervaded by the ether and caloric and affected with cohesion between their molecules or atoms. Gravity is cohesion between masses produced by the pressure of ether; but it is necessary that one of these masses should be a globe of caloric, for when dense and solid bodies come in contact, gravitation gives place to cohesion itself, a more intense form of compression. All bodies except solids, when brought in contact, must be compressed and flattened at their points of contact by the impulsion of the ether, and if the masses brought in contact be fluids of the same kind, they will unite and form a single body. The more nearly the bodies approach in nature to a perfect solid, the greater will be their cohesion; but yet even two globes of caloric, if we suppose such brought in contact, would be affected with the property of cohesion, not only between their atoms, but between their masses; and the two masses would be compressed together until they became converted into one. Two such masses surrounding two dense bodies might in this way produce gravitation, and as all dense bodies at a distance from one another would be thus enveloped in globes of caloric, we have a reason both for this property's acting at a distance and for its being *universal*, that is, affecting all matter except the agents themselves, the imponderable fluids.

There is another way of explaining the reactions of ether and caloric in producing gravitation. We know that water

and air always press hardest in those parts where they are densest. Therefore, water always rushes with most violence from the lowest parts of a cask, and the air presses most heavily near the surface of the Earth. It is by the pressure of the atmosphere in this way upon their lower parts, that light bodies are thus buoyed up. The balloon rises upon this principle; and so does flame, which is burning gas, carrying with it the solid particles which it contains. Also the pressure which the atmosphere exerts upon any body varies with the amount of surface which is presented, being about fourteen pounds to the square inch of surface. Moreover, upon light bodies, as a balloon for instance, the pressure of the atmosphere is upward in a straight line, being exactly opposite to that of gravity. If a body be placed in a globe of caloric, it would be acted upon in the same manner as the atmosphere acts upon the balloon, and would therefore have a tendency to move from the center of the caloric. But this tendency would be counteracted by the ether, which is densest where the caloric is rarest; and since the ether is a more elastic fluid than the caloric, it would press or impell the body in a straight line to the center of the caloric, and the strength and intensity of this impulsion would depend, first, upon the difference of elasticity between the two fluids, secondly, upon the amount of surface presented by the gravitating bodies, and thirdly, upon their distance from one another. The cause of gravitation to the centre of the universe upon the hypothesis of two fluids of unequal density and expansive force has now been explained, and the law of gravity follows of necessity that bodies are attracted and the force varies directly as their mass and inversely as the squares of their distance.

I have supposed the center of the Universe to be the common center of one grand system, to which the whole heavens gravitate, and around which they revolve. This

supposition, however, was not esssential to the support of our double ether hypothesis. We might have supposed separate caloric globes for each solar system, and thus denied any gravitating connection between the Sun and Stars. Proceeding upon this less extensive plan of viewing the law of gravity, we come to the question, which is now to be answered, how the Earth, impelled to the Sun, becomes itself a center of gravity? Why does the Moon gravitate to the Earth, and why does any body gravitate to the Earth? In other words, what is the cause of *Universal gravitation?*

This may be attributed to two causes: First,to the projection of the Earth around the Sun; and, second, to the law of inertia. These forces would resist the impulse of the ether, and by arresting it cause the caloric to become denser around the gravitating body. Supposing the Earth or any other planet to be this body, the condition of the caloric around it is rendered by its projection like that about the Sun, increasing in density as we approach. The Earth being solid, and not elastic, the ethereal pressure is not transmitted through its substance to the caloric on the opposite side, but terminates upon its surface. Hence the ether will be made to react upon the Earth on the side next to the Sun, and on every other side, so that it will press inwardly upon the Earth in all directions, and compress the caloric to it. This, however, would not happen, if the Earth had not its projectile motion, but moved with the full force of its gravity to the center of the caloric mass, which is now supposed to be occupied by the Sun. But this free motion is impossible on account of the law of inertia. Thus the Earth and other planets become centers of gravity, since this condition of caloric cannot exist without it. It is also plain that, if the planets become centers of gravity by virtue of their projectile forces and inertia, that the Sun may, in like manner, become

a center of gravity, to which the planets are impelled, by virtue of a motion around the center, or some other point of the universe. In like manner, the satellites of the planets may receive the same property from similar conditions. All other bodies of sensible or common matter likewise become centers of gravity, and come under the law of universal gravitation, by resisting the impulse or pressure of ether, whether by the projectile motion above mentioned in connection with the Sun, planets and lesser satellites, or whether by that property alone which is called *inertia.* For it is impossible that the force or momentum stored in a falling body of matter by inertia should impart to it a velocity as great as that of the impulse; and, if it be less, it must cause the body to which it falls to gravitate by intercepting the pressure of the ether.

Accepting the above theory, the laws of gravity seem to follow of necessity. The laws are: First, that gravity acts instantaneously; second, that its action between two bodies is not intercepted by the intervention of a third body; third, that bodies are attracted directly as the mass, without regard to the qualities of the substance; and fourth, that the intensity of the force varies inversely as the square of the distance. The first of these properties is explained by the supposition, that the two ethers have constantly, at all points, such a relation to each other, that the bodies are reacted upon by a power in their immediate vicinity, and not by the body in the distance, by which they are supposed to be attracted. We readily see, too, from the same theory, why the attraction between any two bodies is not affected by the interposition of a third body. The third property is explained by the supposition, that the particles of matter are not in contact, but that there are considerable inter-spaces between them, and that the action does not take place immediately between the masses, but between the particles of masses, so that when a

body gravitates to the Earth, its gravity is the sum of the weights of all the particles, and the weight of each particle depends upon its volume or the space which it occupies, and not on any peculiar gravity of the substance; for if the pressure of the ether is supposed to operate in straight lines from a circumference to a center, it is obvious that a large body would obstruct more of this pressure, than a small body. In like manner the amount of pressure would be affected by the position of a body from the center of gravitation, as well as by its magnitude. For it is also obvious, that a body near the center would cut off or intercept more of the pressure, than a more distant body, and that the amount intercepted, or the intensity of the gravitating force, would follow the same law of inverse squares as the intensity of light and heat; for I suppose the force of gravity to act in straight lines to a center, while these forces act in straight lines from the luminous body.

The cause of gravity between masses and that attraction which takes place between particles of matter at insensible distances is the same; the latter being modified, however, by the action of heat, and it may be also by electricity. In regard to the attraction, which exists between the particles of matter, a distinction is made between that which acts between molecules and that which acts between atoms or the primary elements of bodies, the latter being designated *chemical affinity*, and the former *cohesion* and *adhesion*—cohesion, when the molecules are of the same kind, and adhesion, when the molecules are unlike. Thus, we have three kinds of attraction or impulsion—gravity between masses, cohesion and adhesion between molecules, and affinity between atoms. The intensity of this impulsion is greatest between atoms, and least between masses. But, besides this impulsion, there is a repulsion, heat, which operates also between masses, molecules, and atoms, and follows the same law of intensity, being

greatest between atoms, next greatest between molecules, and least between masses. We may illustrate the difference of what is meant by cohesion and affinity by the difference, which exists between a compound and a mixture.

From what I have stated of the laws of impulsion and repulsion, the action between molecules must be weaker than between atoms, not only combining with less force when they attract, but also repelling one another with less force when under the influence of heat. But there is a much stronger resemblance between the actions of molecules and atoms than between masses and molecules, so that cohesion cannot be said to hold an intermediate place between affinity and gravity; for so great is the resemblance between the action of the former two, that it is sometimes difficult to distinguish a mixture, which depends on the interaction of molecules, from a compound which results from the affinity of atoms. With regard to atoms, some elements unite to form compounds, and others do not; some unite readily and with great force, others only under peculiar circumstances. So with regard to molecules; some substances mix, others do not. Substances cannot mix but in the liquid or gaseous form, when the molecules of the same snbstance have a greater repulsion for one another, than for the molecules of the substance with which they mix, or through which they are diffused. In a mixture the force of adhesion is greater than that of cohesion. When the atoms of one substance come into the neighborhood of some other substance, for which they have a stronger affinity than for themselves, a compound is formed, and the compound is stronger or weaker in proportion to the strength of affinity between the heterogeneous atoms. The same is the law of mixtures. Their strength depends upon the strength of attraction between heterogeneous molecules. Diffusion of gases does not depend upon attraction or impulsion, but upon heat or repul-

sion. Gases are diffused, because there is a stronger repulsion between the molecules of the same kind in the state of gas, than between unlike molecules. This belongs to the subject of heat, which I will discuss in the subsequent chapter. So closely are the two forces of heat and attraction associated in all chemical action, that one cannot be well separated from the other. A correct theory of chemical attraction cannot be formed without a corresponding theory, at the same time, of the nature of heat.

CHAPTER III.

HEAT; OR, THE REPULSIVE FORCES OF MATTER DUE TO A ROTATORY MOTION OF ATOMS AND MOLECULES, AND TO THE EFFECT OF SUCH MOTION UPON THE INTERSTELLAR MEDIUM.

As gravitation requires a projection of masses to counterbalance its tendency in the plan of the Solar system or the Universe, so chemical attraction requires a counteracting motion of atoms and molecules as a necessary condition in the constitution of terrestrial substances. The theories regarding the nature of these movements have been various. Some suppose that the movement of molecules in liquids and solids is of an oscillatory character, and that in the gases the particles are entirely free. It is supposed that the elasticity of the gases is due to the incessant bombardment of their loose molecules one against another. Another view is, that the motion resembles that of the planets on their axis, and that atoms or molecules so revolving on their axis may assume three positions in regard to one another, which determine the three conditions of matter as *solid*, *liquid*, or *gas*. The second view is the one which I shall adopt to explain

chemical action and the attractions and repulsions of molecules, while the vibratory motion is that of radiation.

That the atoms and molecules of gaseous bodies should be entirely free in their motions, and that their elasticity is due to the incessant bombardment of the particles against one another, and against the vessels which contain them, is at variance with the hypothesis, which I have presented of gravity—that, whenever two particles of matter come in contact, they are immediately acted upon by the compressive force of two powerful fluids, which tend to hold them together. It is also at variance with the ordinary law of gravity, which is, perhaps, the same for chemical affinity, that attraction acts instantaneously. If this principle be true, the particles could not collide and, at the same time, be free. For a number of reasons, which I will mention, this view of heat seems to me untenable. Can we suppose, for example, that if the particles of gas were perfectly free in their movements, and moved with vast velocity, without any law to control or direct them, that they would always preserve the same distances between them? Would not the volume of any gas, if its molecules moved in so loose a manner, be denser in some parts, than in others? Again, when we consider the immense pressure of confined and condensed gas, and the enormous velocity of its molecules, which produces this pressure, can we suppose, if these molecules were free and moved in straight lines, and were projected like cannon balls against the sides of the vessel containing them, that the particles would not escape through the pores of almost any substance, that could be employed to confine them? What substance, that cannot withstand the bombardment of cannon balls, would be not pierced by the bombardment of gaseous molecules, which are of greater weight in proportion to their magnitude and move with greater velocity, if we suppose them to move in straight lines? Such a

view of heat seems also to conflict with what appears to be the best explanation of the chemical activity of gases, in what is termed their *nascent* state. Nitrogen makes compounds with oxygen, hydrogen and carbon; but these cannot be obtained by simply mixing the gases. The air is chiefly a mixture of nitrogen and oxygen; yet these gases never combine in that state, because their particles are out of range of chemical affinity, and have to be brought nearer together. In order to make them combine, they must be united in their most concentrated form, which occurs at the time of their separation from some other compound. The explanation given of this phenomenon is, that in the *nascent* state the particles of the gases are brought nearer together, than it is possible to bring them by any mechanical pressure when mixed as gases. This would not be true—it would be no explanation at all—if the expansion of the gases is due to a collision of their particles; for their condition would then be always that of their nascent state; they would be coming continually within the influence of one another's attraction.

I suppose, therefore, that molecular repulsion, whether it occur among the atoms and molecules of a solid, a liquid, or a gas, is in every case due to the rotation of these particles, and to the effect of this rotation upon the condition of the imponderable medium which surrounds them. As to the spaces or distances between atoms, I suppose them to vary according to the nature of matter, or rather the magnitude of atoms and the intensity of their motions. I suppose the atoms of ether to be in contact and colliding instantaneously. The proximity of the caloric atoms is also greater than in ponderable matter, but nevertheless separated by spaces, which vary with their cohesion. The atoms of ponderable matter I suppose to be separated by much greater spaces, and revolving each on its axis, in an atmosphere of caloric and ether, like little worlds. The elasticity of ether and caloric

would be due to the rotatory motions of atoms in actual contact or instantaneously colliding; but the atoms or molecules of ponderable matter do not repel one another by actual contact, but through the effect of their rotatory motions upon the caloric atmospheres surrounding them.

The elastic force of ether and caloric would be uniform in each; but there are several conditions of ponderable matter, in which *chemical repulsion* and *chemical impulsion*, taking place between the particles of ponderable matter, would vary. Some of these circumstances I will mention, which will cause me to modify, to some extent, the prevailing theories of *heat;* so that instead of defining it as a *fluid* exclusively, or a *force* exclusively, I will consider the phenomena of heat as the combined effect of fluids and force.

The science of chemistry now makes a distinction between *atoms* and *molecules*. An atom is the smallest particle of an elementary substance; as an atom of hydrogen, or an atom of oxygen. A molecule is the smallest particle of a compound substance, as a molecule of water. I make a distinction in the motions of atoms and molecules. That of an atom is *inexhaustible* or infinite; that of a molecule is subject to *change*. The expansion of ponderable matter, which takes place during heating, may be effected in one of several ways: *First*, by increasing the motion of molecules; *second*, by changing the positions of atoms or molecules relatively to one another; *thirdly*, by increasing their atmospheres and prizing them apart by the inflowing of double ether or fluid heat. Hence, the term *heat* embraces the complex idea of motion and position of atoms and molecules and the condition of the double ether or fluid heat around them; and since chemical repulsion is always the effect of the rotatory motion of atoms and molecules upon the double ether around them, we cannot possess a clear idea of the phenomena by considering one without the other.

We may, therefore, first consider the effect of *motion* upon the double ether, and afterwards the effect of *position;* for in some positions I conceive that the effect of the motion upon the atmospheres of molecules is different from what it is in others. We have supposed a slight cohesion to subsist between the atoms of caloric, and that none exists between the particles of ether; and, hence, we supposed, that the motions of the heavenly bodies are resisted by their friction against the caloric, and not against the ether. This friction, however, we supposed to be very slight, and hence its effect on the motions of the heavenly bodies is very little; but it must increase with an increase in velocity, and bodies moving very rapidly through the caloric must overcome more friction than other bodies moving with less impetus. As this friction produces some effect upon the velocity of the body moving through the caloric, we must admit, in accordance with the principle of conservation, that it must also have some effect upon the caloric, although in regard to the motion of the heavenly bodies it may not be so easy to see what this effect on the caloric may be. In the case, however, of atoms and molecules, which are supposed to move on their axis with inconceivable velocity, we may suppose, that the friction of the atom against the caloric is very considerable, and we may, in this case, form some conception of what the effect of this friction would be, not only upon the atom or molecule, but also upon the caloric atmosphere surrounding it. For, if there exists cohesion, however slight, between the caloric atoms and none between those of ether, the rotatory motion of the ponderable atoms would have more effect in repelling the caloric, than in repelling the ether. Hence it is plain, that the caloric atmosphere surrounding a rotating atom or molecule, instead of following the general law of impulsion by becoming denser as we approach the gravitating body, would be made by the friction to fly off from the ro-

tating atom, so as to increase outwardly in density for some distance from the atom. This would be a reversion of that condition of the caloric atmosphere, which has been described as necessary to produce gravity or impulsion, and the extent of this reversion would increase with the velocity of the atom or molecule, and with the friction consequent thereupon. Now the condition necessary to produce gravity or impulsion requires the caloric to increase in density, as the distance from the gravitating body is diminished, in order that the impulsion of the ether may be greater on the farther, than on the contiguous sides of any two or more gravitating bodies. If, therefore, this condition of the caloric is reversed around atoms and molecules by their rotatory motions, it must be plain, that atoms would gravitate from each other instead of being impelled to each other, and that molecular repulsion must predominate over the opposite force, wherever this reversed condition is supposed to exist. At those parts where the impellent and repellent conditions of the caloric atmospheres run into each other, the gravitating atoms or molecules would be held in *cohesion*, although their surfaces never come in contact.

If, now, we suppose a mass of ponderable matter consisting of many atoms and molecules to have the same affinity subsisting between each and all of these elementary particles, it is plain, that they would all assume and maintain by virtue of their impellent and repellent forces equal distances apart (nor would one atom or molecule collide with another), unless some were subjected to greater pressure than others, as is the case in the gases composing the Earth's atmosphere. At a great distance from the Earth the gaseous molecules in the upper regions of the atmosphere may have a cohesion as well defined as that subsisting between solid bodies; and even upon the Earth's surface the impellent and repellent forces of the gaseous molecules are so adjusted during ex-

pansion and diffusion as to serve as a law in preserving the same density in all parts; so that the pressure of gas upon the sides of any vessel, in which it may be confined, is due not to the random pelting of the gaseous particles, but to their uniform repulsion through their caloric atmospheres.

We see, now, how the atoms and molecules repel one another by the effect of the motions, and how the expansion of masses is thus produced. Let us inquire what part is acted by fluid heat or double ether apart from what has been said. We suppose all space to be filled with matter. Hence, when a vacuum might be caused by the expansion of bodies in heating, the double ether, or heat fluid, flows into the dilating pores as the particles of the mass are parted by repulsion. During expansion there must be a deficiency of fluid heat in every expanding body, and hence it must extract it from surrounding sources. I think it may be shown, that there are cases when the extraction of fluid heat from a body produces cold, and its absorption produces warmth, without decreasing the rotatory motion of atoms in the first case, or increasing their rotatory force in the latter. If we confine a body of gas, and subject it to pressure, it will throw off, by conduction, a part of its fluid-heat, but does not lose any of its atomic motion. If we remove the pressure, the gas, by virtue of its atomic motion, will absorb again the same amount of fluid-heat which it had before; and its temperature, in either case, under the diminished or increased pressure, will be the same as that of surrounding bodies. But during the expansion of the gas, surrounding bodies are cooled; and during the contraction of its volume they will be heated. These changes, I conceive, take place not by the passage of force, but by the conduction of fluid-heat. It is true, force is expended in administering the pressure, but it is expended against the impulsion of the molecules of surrounding substances in prizing them apart

with the fluid-heat expelled from the compressed gas, and it is not converted into their molecular motion; for, although it continues to act after the contraction, no heat is produced. The pressure is balanced by the repellent forces of the gaseous molecules and the impellent forces of the particles of the confining vessel and surrounding matter. When we explode gunpowder, the atoms do not acquire any new impetus or velocity in the gaseous form. They simply assume positions more favorable for expansion; and the sudden expansion of the mass, upon conversion into gas, compresses the atmosphere and absorbs the two ethers or fluid-heat, which the compressed atmosphere throws out. Thus the phenomena of heat are seen under two aspects, as force and as a fluid.

The atoms of simple gases never acquire or lose velocity, but have movements as uniform as those of the heavenly bodies; but the motions of molecules depend upon heat force, and have a greater velocity in the form of vapor, than in that of a liquid or solid. The only effect of heat on atoms is to alter their positions or change the directions of their motions; but on molecules it not only changes position, but imparts motion. Hence the motions of atoms and molecules must give rise to distinct phenomena. But for the purpose of pointing out the relations of the heat force and the heat fluid, the vapor of water may be used in place of the fixed gases. This is seen in the effect of pressure on the boiling of water, which boils at a lower temperature at high elevations, than at the level of the sea. In the boiling of water heat-force, and not heat-fluid, raises the vapor. There is an increase of motion in the watery particles. But the same amount of motion will not produce steam at every elevation. The external pressure of the atmosphere acts as an increment to molecular cohesion, and, therefore, the heat necessary to raise steam must vary with this pressure. Hence

steam formed at a low elevation has a higher temperature, more molecular repulsion, and greater elasticity, than steam formed at high elevations. The pressure, therefore, in this case does not diminish the rotatory force of the molecules, which continue to increase in force as long as heat is applied; but it simply prevents the inflow of fluid-heat or double ether, which is necessary to expansion.

There are three well-marked conditions of matter; the solid, the liquid, and the gas. For these three states, three positions of atoms or molecules have been assumed, suggested, perhaps, by the effects of currents of electricity, which in some positions attract, and in others repel. For the *solid form* we may suppose any two atoms or molecules to have their axis parallel and to rotate in the same direction. This causes the rotatory motion of one atom to neutralize the effect of the rotatory motion of the other atom upon the intervening caloric. They would, therefore, be impelled to one another as if neither moved. For the *liquid form*, we may suppose the same two atoms or molecules to be partly turned, so as to have their axis at right angles. For the *gaseous form*, the atoms are supposed to have their axis parallel and to rotate in opposite directions.

I have already partially explained the effect of the rotatory motion of atoms upon the double ether surrounding them. But we have thus far considered the effect of the rotatory motion of an atom only upon its own caloric atmosphere. We must now examine into the effect of the rotatory motion of one atom upon the caloric atmosphere of another atom, according to the positions, which they occupy towards one another. We have shown that around an atom at rest the caloric atmosphere increases in density as it is approached. This condition produces *impulsion*. And we have said that the rotation of the atom would repel the caloric, reverse the condition, and produce *repulsion*. But we must say a word

more on this point. The rotation of the atom would not only repel the caloric, but it would repel it in a direction somewhat corresponding to its own motion, as we see the sparks fly from the revolving stone of the scissors-grinder. Now, if two atoms be placed and move, as we have supposed for the *solid form* of matter, their contiguous surfaces would move in opposite directions, and would repel the caloric in opposite directions; so that, while each would tend to rarify its own caloric atmosphere, it would make that of the other denser; for the caloric which is repelled from one atom will be met and repelled by that which is repelled from the other. Hence the effect of one's motion would be counteracted by that of the other's motion, and they would be held in cohesion. It is easy now to see, how in the third or *gaseous form,* where the atoms move in opposite directions and their contiguous surfaces in the same directions, that the repulsion of one would assist the repulsion of the other, and that in the second position, that for *liquids,* they would neither oppose nor assist.

There are many circumstances of form, magnitude, motion, and position which may affect the chemical quantivalence of atoms, but, it is probable that the conditions of masses depends more on the relative positions of the particles constituting them than upon the increase or decrease of their motions; and we may readily conceive that a body may exist in the solid, liquid, or gaseous form by simply altering the direction, without altering the amount of motion of the atoms or molecules. In corroboration of this opinion, water, in its three forms, may serve us with a good example. As long as the relative positions of the aqueous molecules remain unchanged, the condition of the body as ice, water, or vapor, remains the same, notwithstanding it may vary many degrees in temperature. What then sustains the aqueous molecules upon the two "precipices," to use a figure

of Tyndall's, from which they fall so suddenly in their conversion from steam into water, and from water into ice, unless it be these relative positions?

I propose to discuss the *polarity* of atoms and molecules under the subject of electricity. But there is one fact which it is well to note here. All points on the surface of a rotating atom do not move with the same velocity. It must be admitted, then, in considering the effect of the rotation of a single atom upon its own atmosphere, that there would always be two points upon its surface, namely, the two poles of its axis, to which the impulsion would be stronger than to other points, and the repulsion of the atom would be greatest in parts about its equator, where the rotatory motion of the atom would have the greatest effect in rarifying its atmosphere. Form, magnitude, and velocity combine to vary the polarity of atoms and to control their aggregation in molecules. Then the centrifugal motion of the molecule, imparted by heat, reacts against the polar forces of the atoms and may shiver the molecule again into its elements or change its form. A rapid revolution on its axis might elongate the equatorial diameter of the molecule, and this result would vary not only with the rapidity of the molecular motion, but with the strength of the polar forces of the component atoms; for by their composition some molecules might be more compact than others. The change produced in the form of the molecule by heat, might produce a change in a mass of such molecules. The expansion in the mass produced by heat may correspond with the expansion produced in the molecule. The same amount of centrifugal force may expand a compact molecule less than one whose aggregation is more complex, and, therefore, weaker; and the same amount of heat may expand a mass of this first sort of molecules less than a mass of this second sort. It may be from some such cause as this that some

bodies expand more than others in being raised through the same temperature, and that some bodies are chemically affected by heat more than others.

But the fixed gases, which are all constituted alike, expand equally in passing from one degree of temperature to another. A volume of oxygen or nitrogen will overcome the same pressure as an equal volume of hydrogen in consuming the same quantity of heat. Hence, upon the comparison of gases by volume, their capacity for heat is the same; but considered in regard to weight, their specific heat, or capacity for heat, increases as their weight is diminished. The products of the weights and specific heats of the atoms of elementary substances are generally equivalents. The measurement of atomic weights is found by reducing the substance to the state of gas or vapor, and is based upon the hypothesis, first enunciated by Avogadro in 1811, and by Ampère in 1814, that equal volumes of all substances, when in the state of gas, and under like conditions, contain the same number of molecules. If we take any two or more such equal volumes, as hydrogen and oxygen, it will be found that the hydrogen will weigh only one-sixteenth as much as the oxygen, and hence the hydrogen atom is said to weigh one microcrith, and the oxygen atom is said to weigh sixteen microcriths. If we examine these equal volumes with regard to their specific heats, or the amount of heat necessary to raise them through the same number of degrees of temperature, we shall find that the amounts for the two volumes are nearly equal. Hence it requires nearly the same quantity of heat to raise sixteen microcriths of oxygen as it requires to raise one microcrith of hydrogen through the same number of degrees of temperature. Hence we must infer, either that the heat force of the sixteen volumes of hydrogen is sixteen times as great as that of the one volume of oxygen, or that the

molecular impulsion of a volume of oxygen is sixteen times as great as the impulsion of an equal volume of hydrogen at the same temperature. One only of these alternatives can be true; and the latter I assume to be correct. Hence it appears that with one-sixteenth of the impulsion (for a hydrogen atom is only one-sixteenth as heavy as an oxygen atom), and with equal repulsion, hydrogen would absorb sixteen times as much double ether or heat fluid as oxygen.

There are two causes which co-operate to produce the expansion of bodies. Heat force, by increasing the circular motion of molecules, would cause expansion. Again, expansion might be produced by increasing the double ether or densifying the caloric composing the molecular atmospheres. A body is heating when it is expanding by any of these modes. When we compress gas, we cool the gas and heat surrounding bodies, not by diminishing the molecular motion of the one, or increasing that of the other, but by producing a flow of the heat fluid or double ether. The double ether is pressed out of the gas and into surrounding bodies, so that these expand as that contracts. The gas, however, has not lost molecular motion by the process, nor have surrounding bodies acquired it. As soon, therefore, as the pressure is removed from the gas, its molecular motion causes it to expand, and this expansion abstracts from surrounding bodies the double ether, which had been imparted to them by the compression of the gas. Therefore, the gas is capable of producing, by its expansion, a degree of cold corresponding to the amount of heat emitted while its volume was being contracted. The flow of the heat fluid in each of these two cases depends upon the same principle, *the plenum of space.* When, therefore, we reduce a mass of ponderable matter to a smaller volume, we expel the double ether which fills its pores; when we enlarge its volume we increase its capacity for the interstellar medium,

which is, therefore, absorbed. The pressure which reduces the volume of the gas, and the molecular force which expands it, are the energies in the above example, which produce the ebb and flow of the interstellar medium.

In every heating effect two agents are to be considered—the heat force and the heat fluid. The movement of the heat fluid is called *conduction*, and it is found to take place through some arrangements of atoms and molecules more readily than through others. Let us suppose two volumes of gas to be submitted to the same pressure, and surrounded one by good conductors, and the other by imperfect conductors. It seems reasonable to suppose that the gas surrounded by the good conductors would be more compressed than the gas surrounded by the non-conductors. At the same time, since it is probable, that ether would flow, on account of its greater rarity, more readily through the non-conductor than the caloric; the caloric would, probably, be found more dense in the volume of gas surrounded by the non-conductor than in the volume surrounded by the conductor. This difference of caloric density in the two volumes is the cause, I suppose, why one volume would be more compressed than the other. For I have supposed expansion to be produced not only by increasing the amount of the double ether, but by densifying the caloric; in fact, I suppose this thickening of the caloric to be one means of increasing the amount of the double ether constituting the molecular atmospheres; because it would seem that the same rotatory motion of the molecules must produce a more intense repulsion through a dense medium than through a rarer, since against the former the friction of the molecule would be greater.

If we should connect the two volumes of gas by a conductor, it is probable that the caloric would flow through it from the insulated gas to the uninsulated, and a

current of ether would flow through the conductor in the opposite direction. If we could suppose the insulators and conductors perfect, then the strength of the current flowing from one volume to the other would be exactly equal to the pressure exerted upon the insulated gas. Calling the caloric positive electricity, and the ether negative electricity, the connection of heat and electricity may now be seen. The conduction of heat consists in the flow of the double ether, or the two fluids constituting it, in the same direction, and is accompanied with expansion. The conduction of electricity consists in the separation of the double ether and the flow of the fluids composing it in opposite directions; and as one fluid simply takes the place vacated by the other, it is not accompanied with expansion.

Both in the phenomena of heat and in the phenomena of electricity the same fluids and the same kind of motion is required, and the same arrangement of atoms and molecules, which constitutes a conductor or a non-conductor of heat, also constitutes a conductor or a non-conductor of electricity.

The physical and chemical changes which are always taking place in the Earth afford us numerous examples of the conversion of heat into electricity, and some of these, perhaps, may be explained by the experiment which I have supposed to be made with the compressed volumes of gas. It may be by a process of this sort that electricity is developed in the atmosphere. Vapors ascend charged with latent heat, which is liberated when they are converted into liquid and take the form of cloud or rain. Here we have then a body of vapor condensed and surrounded by a non-conductor. The vapor is in place of the gas supposed above; the compressive force is developed in the physical change of vapor into water, and the atmosphere is the vessel in which the vapor is insulated. The ether, on account of

its extreme tenuity, escapes; the caloric is condensed. Thus the air is charged with positive electricity. An immense amount of electricity may be formed in the atmosphere in this way from the application of steam, the steam being condensed, and heat converted into electricity.

Experiment might show that if the hydroelectric machine were so modified as to effect a greater condensation of the steam, the amount of electricity collected would be much increased. It is usual to ascribe the generation of this electricity to friction of the steam upon the sides of the pipe through which it issues. If this were so, an immense amount of negative electricity would be collected on the sides of the pipe, for friction always produces the two kinds of electricity in equal amounts, and the steam could not, according to this principle, be made positive unless the pipe conducts away the negative electricity. As this appears not to be the case, I have conjectured that the electricity is mainly produced by the condensation of the steam and the conversion of heat. It is the fluid heat that is converted into electricity. The heat force is radiated.

CHAPTER IV.

ON RADIANT HEAT AND LIGHT.

I HAVE considered on the basis of the double ether hypothesis, the nature of heat as a mode of motion in ponderable matter, which I have described as a rotatory motion of atoms and molecules. It remains now to consider its nature as *radiant heat*, or as a mode of motion in imponderable matter. Radiant heat is the transmission of force from one molecule of ponderable matter to another by the undulation of an elastic medium. This transmission, or radiation, takes place by rectilineal motion, and the heating effect consists in the change of this rectilineal motion into the rotatory motion of the molecule. The molecule throwing out heat converts its circular motion into the rectilineal or undulatory motion of the interstellar medium, and the molecule absorbing heat reconverts this rectilineal into circular motion again. Thus motion lost by one molecule is transmitted through the interstellar medium and acquired by another; and simultaneously with the communication of the heat force, a communication of fluid heat also occurs between the two particles. The body whose molecules acquire heat force, expands and absorbs the fluid; and the body whose molecules lose force, contracts and expels it. If no ponderable matter intervene between the two bodies, the double ether or heat fluid flows immediately from one to another. But when two or more molecules at a distance and separated from each other by the intervention of ponderable matter lose and acquire fluid heat, the third body, through which the fluid heat flows or passes, is called a

conductor, and the transmission of heat through it is called *conduction*. But of this, more by and by.

From the nature of the law of gravity, that bodies are attracted inversely as the square of the distance, the velocity of a planet is such that the radius vector of its orbit always describes equal areas in equal times, whatever be its distance from the Sun. Therefore, the planet moves in the neighborhood of its perihelion with greater velocity than in that of its aphelion. Likewise motion and attraction are associated in the constitution of all material substances, and the attraction between their particles, when modified by heat, takes the form of chemical affinity. But we do not know the nature of the motion of these particles as well as we understand the motions of the heavenly bodies. Some philosophers have thought that heat vibrates the particles of matter or projects them in straight lines, somewhat after the manner of the orbital motions of the heavenly bodies; others, as Prout, in the "Bridgewater Treatises," whom I have followed in explaining the theory of heat and the three forms of matter, suppose this motion to be rotatory, like that of the heavenly bodies on their axis.

Assuming that the same law of inverse squares applies alike to the gravitation of masses and the affinity of particles, we must infer that masses and particles are likewise governed by the same laws of motion, and that as the more distant planets require the less velocity to sustain them in their orbits, so the particles of matter, as they recede from one another by the action of heat, require less heat force to carry on the further separation. If the attraction of particles for one another varies inversely as the square of the distance, the heat force necessary to sustain them in a state of isolation must follow the same law. The investigation of this law then ought to throw some light on the nature of the motion of molecules. It seems to warrant the

conclusion that the heat between the particles of masses follows the same law of diminution as the heat which is radiated between distant masses, and that the motion of these particles cannot be in right lines, as some philosophers have supposed them to move in the state of gas.

If we consider the law of the expansion of gas, that under a constant pressure its volume increases directly as its temperature, bearing in mind at the same time that its particles attract one another with a force which varies inversely as the square of the distance, we must conclude that the heat force diminishes in the same manner as the attractive force diminishes with the distance. This diminution is best explained by the supposition that the heat force which forces apart the particles of matter is the same as radiant heat, and passes from particle to particle, not by their contact and collisions, but through the oscillation of the interstellar medium. The waves thus produced in the interstellar medium between the particles of a body being the same, or at least of the same nature, as the waves of light, the intensity of their force follows the same law of diminution. The waves which produce light are emitted from the molecules on the surfaces of masses; but those waves which are emitted by the molecules within the mass, do not come to us so as to affect the organs of vision; neither do they emerge from the mass, but act between the molecules and endow them with such repellent properties as to exactly neutralize the force of attraction. This is the condition of bodies when they are at the point of assuming the form of gas or vapor; the repellent and impellent forces of the particles balance one another, and the particles are free. Beyond this point, if the repellent force becomes greater than the impellent force, the particles recede from one another with a force which increases directly as the temperature, and the mass assumes the elastic form of gas;

but if the impellent force is greater than the repellent force, the body will take the solid form, and the particles will be pressed together with a force which varies directly as the temperature. Therefore, the specific heat of bodies varies inversely as their atomic or molecular weights, whether the body be in the form of solid, liquid or gas. By this supposition of the nature of heat, we may explain the three laws of Marriot, Charles and Avogadro without discarding the force of attraction.

But according to the other theory, which supposes the particles to beat against one another, the bursting power of the gas would not be doubled by doubling the motion of its particles, unless the particles have lost all power of attraction for one another, and the gas's expansion is retarded only by external pressure. We are required to grant that the particles which in the state of solid had the property of attraction, in the state of gas are wholly without it; and we are presented with no account of this loss which is at all satisfactory. For if this property of attraction acts instantaneously as the law of gravitation, it would certainly be unwarrantable to conclude that in the state of gas the particles get beyond the influence of the property, and at the same time assert that the expansion of the gas is due to the collision of its particles. Again, this theory requires us to suppose that the particles of one sort of gas require more velocity at the same temperature than the particles of another. According to the law of Avogadro, equal volumes of gases under the same condition of temperature and pressure contain the same number of molecules. If we take two such equal volumes of oxygen and hydrogen, the volume of oxygen is found to weigh sixteen times as much as the volume of hydrogen. Calling the weight of the hydrogen atom one, that of the oxygen atom is sixteen. How can we explain the elasticity of these gases then upon

the impact theory of heat, unless we assume that an atom of hydrogen acquires sixteen times the velocity of an atom of oxygen under the same temperature? for the expansion of the gas would be in proportion to the momentum of its particles. The question, why there should be more latent heat in gases of small particles than in gases of large particles, and why the latter become saturated with heat and arrive at an equal temperature before the former, is generally explained by the assumption that all atoms, both large and small, have the same capacity for heat. This capacity must be construed to mean *momentum* by the impact-theorist; but I shall construe it to mean *velocity*, because the view which I have taken of heat recognizes the action of both forces, attraction and repulsion, at the same time.

Assuming, then, that the particles of matter have a rotatory motion, and that heat is communicated from one to another by radiation through the interstellar medium, the meaning of the term *specific heat* may be thus illustrated. If oxygen and hydrogen be subjected to the same temperature for any length of time, the atoms of oxygen acquire the same velocity as the atoms of hydrogen. But in the same weight of the two gases, the hydrogen molecules are sixteen times as numerous as the molecules of oxygen; therefore taking a pound of each gas, the specific heat of hydrogen is sixteen times that of oxygen. According to the impact theory, the relation between the weights and specific heats of atoms is explained on the assumption that the atoms of gases are entirely free and acted upon only by heat; and, therefore, an atom or molecule of hydrogen must move with sixteen times the velocity of an atom of oxygen in order to overcome the same pressure. I have already expressed my dissatisfaction with this hypothesis. For why should an atom of oxygen, when submitted to the same temperature for an indefinite length of time, acquire only one-sixteenth

the velocity of hydrogen? By admitting the action of attraction between the particles, I explain the capacity for heat of the two gases differently. For I suppose that the gravity of the particles of oxygen for each other is sixteen times as great as the gravity of the particles of hydrogen, and that, therefore, sixteen times as much momentum in the case of oxygen is necessary in order to put its particles in the same relation to one another as those of hydrogen. Then when the particles have this relation to one another, if we double the motion of these particles we double the temperature and the expansive energy of the gas. This explains why multiplying the specific heat of different substances in the state of gas by their atomic weights produces equal results. Now this law of equality of products holds good not only for gases, where we might have supposed the particles absolutely free from the influence of one another's attraction, but it holds good for solids, too, where we know the particles are not free from attraction; and the view which I have taken of heat seems to explain the law for all three forms, and applies with the same simplicity to one as to another.

The term *radiation* is used to denote the passage of force through the interstellar medium, and if in this way heat is communicated from one particle of matter to another, the particles of matter cannot be in contact, but must be separated by inter-spaces many times greater than the particles themselves. As these inter-spaces increase in magnitude, and the particles of any mass are removed farther and farther apart, the intensity of the radiation would vary inversely as the square of the distance between the particles, and, therefore, the conductivity of bodies would diminish with their expansion. Hence gases are worse conductors than liquids, and liquids are worse conductors than solids. It is true liquids are sometimes heavier than solids, which would seem to imply that their particles are

nearer together; but this is explained by the fact that solids have structure and liquids have not, so that the comparative lightness of the solid is due to its porous nature. Liquids and gases probably conduct equally well in all directions, but solids do not. This also is due to structure. If we examine the process of crystallization, we notice that the crystals are formed in long fibres, which lie parallel to one another. It is plain, from the law of radiation above stated, that the heat would be conducted best in the direction of these fibres. This is illustrated both in the melting of ice and the crystallization of snow. The formation of the "ice flowers" in the beautiful experiment of Tyndall may be due to this cause, the ice in melting following the lines of its crystallization.

The specific heat of bodies and their conductivity depend greatly on their physical condition. The same substance has not the same specific heat or the same conductivity for the solid, liquid, and gaseous form. Hence, in comparing substances with respect to their specific heats, they must be reduced to the same one or other of these three states. Gold as a solid cannot be compared with mercury as a liquid, but the mercury must be solidified; nor can hydrogen and oxygen, which cannot be solidified, enter the same table of specific heats with the metals. In comparing bodies in respect to their conductivity, we must have respect not only to their form, but also to their temperature. As their temperature increases their conducting power decreases. This may be due to the fact, that by the expansion of the conductor by heat the particles of it are moved farther from one another. In comparing the conductivity of solids and liquids where their expansion is little, it may not be so necessary to take their temperature into consideration; but it must be very essential in comparing that of gases, whose volume increases directly as their temperature when under

the same pressure. If the temperature of two volumes of gas under equal pressure is such that the temperature of one is twice that of the other, the bulk of one is also twice that of the other. In this condition the particles of one of the volumes are twice as distant from one another as the particles of the other. Applying the law of inverse squares, the conductivity of the more rarified gas would be in this case only one-fourth that of the denser gas. But if the elasticity of gases is due to the collisions of their particles, it does not appear, why, under the same pressure, a rarified volume of gas should be a worse conductor than one whose particles are closer together.

It may be easier to imagine how a rectilineal vibratory motion of the interstellar medium may cause the vibrations of the molecules of ponderable matter, than how it can cause a circular motion. Yet we have many examples of the interchange of circular and simple projectile motions in sensible masses. Water, for example, may give a circular motion to machinery in three ways—by its impulse, in the case of an undershot wheel; by its weight, in the case of an overshot wheel; and, third, by reaction in a peculiarly arranged horizontal wheel. On the other hand, the motion of wheels or machinery may communicate a rectilineal motion to water. Thus we may compare the inter-action of the interstellar medium and molecules to that interchange of motion which takes place between water and water-wheels, and thus the mode of conversion of radiant heat into a circular molecular motion may be faintly conjectured. It may be that the varying densities of ether and caloric around atoms and molecules produce refraction, and by this means, in some way, cause the force, which is communicated by radiation, to proceed around the atoms and molecules with a whirling motion, and impart, by friction, a rotatory motion to them through their atmospheres. The *refraction* of the

heat force would depend upon the condition of the heat-bearing medium or caloric atmosphere around the molecule; but the *friction* by which the heat force is communicated to the molecule must, in a great measure, depend upon the construction of the molecule and the roughness and smoothness of its surface.

Now, the condition of the molecular atmospheres has already been described. For I have explained that these atmospheres increase in density outwardly or from the atoms when they are in motion, and inwardly when at rest. But since we have supposed them always to be in motion, whether in the solid, liquid, or gaseous state of matter, we must suppose that the radiating medium, if this be caloric, is in the former condition in the neighborhood of atoms and molecules. Since an atom is a simple body, we are able to form an almost exact idea of the nature of this condition. For by direct reasoning, we may define the different effects produced by the rotating atom upon the caloric at different points of its surface. But a molecule being a compound body, the nature of its atmosphere must depend upon the positions of the atoms which compose it, and the refracting power of its atmosphere must depend not only upon its own motions, but upon the motions of the atoms. There is, however, one general effect which may be described; for the caloric atmospheres of all atoms and molecules vary in density, since by this condition attraction and repulsion are produced.

Owing to the unequal density, therefore, of these atmospheres, we suppose the heat force to be refracted in passing through them. But shall we suppose, that it is refracted to the molecules or from them? The answer to this question depends upon the medium assumed for the passage of the force; for, in regard to density, the relations of ether and caloric are opposite, the one increasing in

density as the other diminishes. But since caloric is more nearly related to ponderable matter than ether, it must from its nature be the medium of force, either heating or chemical, or both. In observing the passage of the heating and chemical rays through transparent bodies, we see that the heating ray is less refracted than the chemical ray. Now, the medium of the two rays may be the same. But if there is a separate medium for each, it is plain from this difference of refraction that the medium of the heat ray is the one which is more nearly related in its nature to ponderable matter. Let it be granted, therefore, that caloric is the medium of heat force, and we may proceed to answer the above question.

From the fact, that heat and light in passing through diathermic and translucent bodies, like gas or water or glass, are more refracted in proportion to the density of such bodies, we might suppose, that the law of refraction would be the same through the imponderable medium, and that the heat force would be refracted from the molecules, because their atmospheres increase in density from them. But the cases are not analogous. For the particles of glass, gas and water are not truly the vehicles of the heat force, but this force is transmitted through the imponderable medium; and if it is refracted more in water, than in air, it is because the latter presents less obstruction. The particles of ponderable matter are, however, the vehicles of sound, and stand in the same relation to sound as the caloric stands to the radiation of heat; that is to say, the vehicle of sound is ponderable matter, and the vehicle of radiant heat is imponderable matter. We must look, therefore, for the same relations to govern the refraction of heat in imponderable matter, which govern the refraction of sound in ponderable matter. Sound travels through air at the rate of one thousand and ninety feet in a second; and through

water four times, and through iron ten times as fast as through air; and, generally, the rapidity of sound varies with the elasticity and density of the medium as in the case of air, water and iron. If sound, then, increases, with the density of the medium, through which it is conveyed, we may suppose, that the rapidity also of the heat force, in travelling through its proper medium, would increase with the density of the caloric. Hence in passing through the caloric atmospheres of atoms and molecules, the heat force would be refracted to these bodies and not from them; and I suppose, that the meeting of the refracted forces in the proximity of the atoms or molecules might in some way whirl or eddy around them, and impart in this way a circular motion.

We have thus formed some idea of the mode, in which the heat force may be communicated through the interstellar medium, from one rotating particle to another. But we may well suppose, that the passage of radiation through ponderable matter is not always accompanied with a conversion of the rectilineal motion of the interstellar medium into the circular motion of ponderable molecules. Sometimes the ponderable molecules are simply agitated, and take the same kind of oscillatory motion as the interstellar medium.

This is the case when bodies have the properties of transparency and diathermancy. They transmit the heat through them without being heated, or rendered luminous. They are not heated or luminous, because their motion is of the same character as radiant heat; but they refract because they do not move so readily. In order that a body may be visible it must resist the vibrations of the interstellar medium by reflection so as to give a character to them corresponding to each point on its surface. Hence transparent bodies, which give no character to these vibra-

tions but take the same motion as light, are invisible. Now if this reasoning is good to account for the invisible nature of transparent bodies, that their motion is vibratory like that of light, it must hold good conversely, that bodies which are heated by radiation and become visible, must at the same time take a motion different from that of light; that is to say, in the case of such bodies, the vibratory motion of radiant heat is transformed into a rotatory motion, otherwise the motion would pass through them and render them transparent.

The waves of the interstellar medium, which produce white light, are not all of the same length, but decrease in magnitude from the red to the violet. Can this be explained by the assumption that the motion of molecules is vibratory? Can we suppose, that a molecule becoming luminous can vibrate in so many different ways as to produce all the rays of the solar spectrum at once from the red to the violet, and even beyond the red on one side and the violet on the other? If this question is to be answered in the affirmative, then we have to assume that each ray of the solar spectrum is the product of a different molecule or atom in the luminous body. For it would seem that as each string of a musical instrument has its own note, so each vibrating molecule must emit its own peculiar ray. Each luminous body, therefore, must be a more complex arrangement than the musical instrument, having as many different sorts of molecules or atoms as it emits rays. How does such a hypothesis then comport with the theory of atoms, where all the atoms of a simple substance such as carbon, which emits a white light, are represented as having the same weight? Neither does this hypothesis explain why those atoms or molecules which produce the red rays should be set in motion first, or those which produce the violet, last.

Let us consider then, on the other hand, how and in what

order the waves of light may be produced by a rotating molecule. This action of the molecule on the interstellar medium may be compared to the action of a water-wheel, composed of paddles of unequal lengths. The waves of water would correspond in magnitude, perhaps, with the length of the paddles, those paddles stirring the water deepest producing the greatest waves, but the frequency of the waves depending on the rapidity of the wheel's rotation. So with the rotating molecule. For the aggregation of atoms in forming a moleculc would give it a rough surface, corresponding to the paddles of the water-wheel. This surface, as the molecule rotates with rapidity, produces waves of light, varying in length with the distance of each component atom from the axis of the molecule. Now the atoms, which are most distant from the axis of the molecule, and which have therefore the longest range as the molecule rotates, are those atoms on its surface, which lie about its equator. These atoms, therefore, move with more rapidity and excite the ether waves with more frequency than atoms on other parts of the surface of the molecule, in what might be called its polar regions. Now the motion of the moleculc upon its axis, might not be sufficiently rapid at first to effect the vibratory movement of the caloric, or ether, whichever we assume to be the medium of light; but in attaining the necessary velocity to produce light, it is plain, that the atoms in the equatorial part, would attain that velocity first. As the colors of the spectrum and the length of the ether waves depend upon the intervals of time when an atom leaves and returns to a point or when one atom arrives at a point vacated by another, it is plain, that as the rotatory motion of the molecule increases, a red band of light, as the molecule becomes luminous, would first encircle its equator, while all the rest of the molecule would be dark. But as the molecule further increases in motion,

so that the dark portion becomes luminous, the red band of the equator gives place successively to a band of orange, a band of yellow, and so on through the spectrum. If then we could see a molecule becoming luminous, we should first see a narrow band of red marking the equator of the molecule. This band would grow wider and wider, and would presently be divided in the center by a band of orange; then a band of yellow would divide the orange, and this process would continue until a spectrum would appear on each side of the molecule, with the red ray nearest to the pole and the violet nearest to the equator. Here, then, is an argument drawn from the properties of visible heat in favor of the rotatory motion of molecules; for in the order here mentioned, the colors of the spectrum are produced.

A rotatory motion being assumed as that of the molecule of luminous matter in the production of light, we may proceed to explain the cause of its *polarization*. We know, that cold solid bodies as a rule are opaque, and that gases are invisible. It seems to be in passing through the intermediate stage between the gas and the solid, that bodies become luminous. Sometimes, this transition is slow, and fusion or liquidity becomes one of the fixed states, as is the case with metals, many of which arrive at the liquid state immediately after they attain a white heat; sometimes it is instantaneous, as is the case with carbon. But in most cases those bodies, which require the highest temperature to produce the transition, emit the most brilliant light; while on the other hand, those bodies which are capable of assuming the liquid or gaseous state at very low temperatures as a rule emit no light at all. These characteristics of luminous and non-luminous bodies here pointed out, as far as they hold good, are probably due in part to the velocity of molecules and partly to their shape. Take water as an example. This we know is incapable of producing

light either in its solid, liquid or vapor state. Now we think we have some idea of the constitution of the water molecule. It is supposed to consist of one atom of oxygen and two of hydrogen. A molecule of this structure would be incompetent to produce all the ether waves of white light, and, according to our assumption, it would only be competent to produce two. Yet these molecules at different temperatures as happens in the atmosphere would be capable of absorbing rays of different magnitudes. But owing to the low temperature at which water passes into the liquid state, the motions of its molecules would be too slow to vibrate the ether at all. But a platinum or carbon molecule capable of emitting a white light, must be composed of many atoms. I have said, that it seems to be a rule, that bodies become luminous at the transition stage from solid to gas, that is to say, when the molecules of bodies are in that position which is assumed in the liquid state. Let us suppose then, that we could see two luminous molecules of carbon, A and B, in this state. They would each appear to us to be striped with bands of color, running around the molecule parallel to its equator; but the bands of color on the molecule A would be at right angles to the bands on the molecule B, because the two molecules are assumed to be in the liquid state, having their axis at right angles. This seems to me to illustrate, if not to explain, the "two sides" or "right and left handedness" of a ray of light, the rays from B being at right angles to the rays coming from A. Hence the rays from one of these molecules might pass freely through a medium, which would exclude all the rays from the other, and *vice versa*. The *polarization* of the light, then, consists in presenting a medium in such a position as to reflect the rays from one molecule, and to refract those from the other.

Now as to the difference of chemical and luminous rays

on the one hand, and radiant heat on the other, I am inclined to attribute them to widely different agents. The former I attribute to the oscillations of ether produced by the motions of atoms from place to place; the latter to the undulation of caloric. It is a somewhat vague idea of this sort, which has led me to apply the term *ether* to one fluid of the double medium, and *caloric* to the other. For it is a very noticeable fact, that although light and radiant heat usually accompany each other, the quantities of each emitted by different bodies are by no means proportional, and sometimes one is emitted without the other. Vision may not be a fair criterion; but the chemical effects of one class of rays seem to associate it with atoms, while the heating effects of the other class connect it with molecules. I am inclined to think, that chemical action takes place by the oscillation of ether, which does not, like caloric, impart motion to molecules of a rotatory character, but shakes the atoms together and changes their positions in molecules, just as nitro-glycerine is exploded by concussion. Light also by chemical action produces explosion. We may explain the difference in the causes of the heating and chemical effects, by the supposition that a body is heated, when the vibratory motion of the interstellar medium is converted into a rotatory motion of molecules; and that a body is chemically effected, when no such conversion takes place, but the molecules receive an oscillatory motion, which being of a less regular nature than a rotatory motion, would tend to bring the atoms of one molecule under the influence of those of another.

CHAPTER V.

ELECTRICITY EXPLAINED ON THE DOUBLE ETHER HYPOTHESIS, THE BASIS OF THE PRECEDING THEORY OF GRAVITY AND HEAT.

In the conduction of heat two bodies are concerned, the heated body and the cold body. In the conduction of electricity the two bodies concerned are the positive body, charged with positive electricity, and the negative body, charged with negative electricity. In both classes of phenomena the same fluids and the same kinds of motion occur, so that heat is sometimes converted into electricity and electricity into heat.

If two masses of the same kind of matter be brought in contact, the one heated and the other cold, the cold body will absorb double ether from the heated body, until their bulks or volumes bear the same ratio to their respective weights. They will then be at the same temperature; for neither will then have more tendency than the other to impart the fluid or to radiate force. But we may suppose the two bodies brought in contact to be of different kinds, as one of zinc and the other of copper. These metals differ in the following respects: We observe that copper is a more compact metal than zinc. Its particles lie closer together. Although its atoms are smaller than those of zinc, it requires less heat to raise it to the same temperature, and in passing through one degree its expansion is much less. As a con-conductor it stands in relation to the other metal as three to one. Let us suppose, that the specific heats of the two metals have regard to their molecular motions. The zinc, then, requires more molecular motion to raise it one degree

of temperature than the copper; its interior work, therefore, to use an expression of Tyndall's, must be greater. Let us see what this is. In the first place it expands more than the copper, and absorbs more double ether in passing through one degree of temperature; and, secondly, being a much inferior conductor to copper, it draws its supply of caloric less readily. Hence we may infer, that both metals being heated to the same temperature, and placed under circumstances equally favorable for acquiring caloric, the better conductor or copper would acquire more caloric than the zinc in proportion to the amount of ether acquired. On the contrary, zinc, at the same temperature, has acquired more molecular motion, and its specific heat is greater than the copper's. Hence if we consider two insulated plates of copper and zinc at the same temperature, the zinc has the more molecular motion, and the copper a denser caloric atmosphere or more positive electricity. On account of the caloric being rarer in the zinc, than in the copper, the molecular motion of the zinc to sustain the same temperature as the copper must exceed that of the copper in the same proportion as the density of the caloric atmospheres of the copper molecules exceed those of the zinc molecules. Such then would be the relations of two insulated plates of zinc and copper, while their conditions are dependent on the continual fluctuations of temperature in surrounding media, either air or some other non-conductor. But if we bring them in contact these relations are changed and their electrical equilibrium disturbed. For the two metals in contact do not acquire and lose force and fluid according to the same law as when they are insulated, and when brought in contact the copper will be positive to the zinc.

Electricity consists in disturbing the equilibrium between the two fluids, so that one body gets an excess of caloric and the other body gets an excess of ether. Hence no expan-

sion or contraction occurs if the two bodies so vary in their molecular motions as to always maintain the same amount of the mixed fluid though the proportions of the mixture vary. The body, which has a tendency to impart caloric is positive, and the body which has a tendency to impart ether is negative. It is not necessary, that the positive body should have more caloric or the negative more ether than the body in the opposite electrical condition. What constitutes its positive or negative condition is the *tendency to impart* the one or the other fluid. While no such tendency exists they are in electrical equilibrium. The insulated plates of copper and zinc were in electrical equilibrium. We bring them in contact and it is disturbed; but it is restored again, when a sufficient quantity of the opposite fluids has been interchanged by the two metals. But until the equilibrium is restored, the copper is positive to the zinc and the zinc negative to the copper. Ether and caloric flow in opposite directions. The zinc derives caloric from the copper, and the copper derives molecular force and ether from the zinc. But when we again separate the two plates the electrical equilibrium is again disturbed, and the zinc will be found to be positive and the copper negative. How are we to explain this? Positive electricity or caloric must have passed out of the copper into the zinc, and negative electricity must have passed out of the zinc into the copper, when they were in contact. And since no expansion of the zinc has occurred, and no contraction of the copper, the molecular motion of the zinc must have diminished and the molecular motion of the copper increased by the contact. After they are separated, however, the opposite electricities have a tendency to pass back again into their former conditions. The zinc molecule again assumes its velocity and expels caloric; the copper absorbs caloric and radiates its molecular force. The zinc has become positive, and the

copper negative. Hence it appears, that it is not an absolute excess of positive electricity or caloric, that renders one body positive and another negative; for the negative body may have more positive electricity than the positive body. For without regard to the quantity of electricity of either kind in either body, the mere separation of the two metals, or the bringing of them in contact, renders that negative, which before was positive, and *visa versa.* The question is why *contact* and *separation* produces change in the electrical condition.

I have shown, that heat is not to be explained by the supposition of force or fluid alone. It is thus also with electrical phenomena: the equilibrium of the fluids, and the disturbance of this equilibrium depend in a great measure upon the movements of the molecules of the electrified body. There is always a certain correspondence between the motions of molecules and their atmospheres. Increase their motions, the mass expands and the imponderable fluids are absorbed; decrease their motions, the mass contracts and the fluids are expelled. When, in accordance with this correspondence, two contiguous bodies neither absorb nor impart caloric and ether, they have the same temperature. Capacity for heat is a term which denotes that some bodies arrive more readily at the same temperature than others; and that amount of force, which compared with a standard, is necessary to raise the temperature of any substance through one degree is called its specific heat. The different capacities of bodies for heat may be due to several causes. In the case of the permanent gases, where the atomic motions are presumed not to vary and their positions in the molecules to be the same, each gas molecule being composed of two atoms, I have supposed the different specific heats to be due to a difference in chemical impulsion between the atoms. For the atomic and molecular motions

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and positions being the same, and the conductivity of the gases equal, there appears to be no cause but the difference of atomic weight or chemical impulsion to prevent the heavy gases from expanding equally with the light. In the case of solid bodies on the other hand, as copper and zinc for instance, there is a difference in specific gravity, which does not accord with their atomic weights; and a difference in the positions of atoms in the molecules, so that the same molecular motion in the zinc produces more expansion than in the copper. The molecule of zinc being, therefore, less compact than the molecule of copper, may acquire and lose motion more readily. The greatest velocity which a molecule can have, I am inclined to think, is equal to the velocity of radiant heat. All space is filled with these radiations, moving with the same velocity in all directions, and imparting motion to molecules; but owing to the different positions and conditions of these, some acquire more than others under similar circumstances, and lose more readily, in turn, that which they acquire. But besides the mode of acquiring molecular motion by radiation from distant and separate bodies, it is also acquired by contact. The property of acquiring it in these two ways may vary in different bodies. One sort of matter may excel another in losing and acquiring heat force by radiation; another may excel in communicating molecular motion by contact. Hence it may be that the electrical equilibrium of copper and zinc is destroyed by bringing the metals in contact and separating them again, thus constantly changing the motion of the molecules upon which the equilibrium depends. The passage of ether and caloric from one body to another in opposite directions for the purpose of restoring equilibrium, or establishing those relations between molecular forces and molecular atmospheres, which certain conditions require, is what constitutes an electric current. The conduction of electricity

is effected much more rapidly than the conduction of heat, because no expansion occurs, and less interior work is done. But when the conductor resists the passage of the current, electricity is converted into heat.

The conduction of heat is the passage of the two ethers in their mixed condition through the conductor, both fluids moving in the same direction. A current of electricity, on the other hand, consists of the passage of the same fluids, but in opposite directions and in equal amounts. When heat passes, therefore, the body from which it passes is diminished in bulk and the heated body is increased. The contraction and expansion are not always equal, however, in the two bodies, which shows, that it is the heat force, and not the heat fluid, which always remains a constant quantity; the latter being mainly the medium through which the effect of the former is produced. But when electricity passes from one body to another, neither body is expanded or contracted, because each receives as much of one kind of fluid, as it discharges of another. "An electric current," says Faraday, "in circulating through a thick or thin wire, exhibits the same deportment as a fluid flowing through a wide or narrow tube." As a given quantity of fluid requires more time or greater pressure to pass through a narrow tube than through a large, so a thin wire offers a greater resistance than a thick one to the passage of a current of electricity. The current is thus retarded and diminished, one portion only passing through the conductor, the other being converted into heat. This is an example of the conversion of electricity into heat. The heating effect is probably produced by the accumulation and combination of the two fluids in the heated body, instead of continuing onward in their opposite directions to the bodies oppositely electrified.

Instances of the conversion of heat into electricity also occur. One of the most obvious of these is that which occurs

in the thermo-electric pile. Thermo-electricity probably consists in the separation of the double ether into its two components. The thermo-electric pile is formed by the junction of two metalic bars, one of antimony and the other of bismuth, welded together at one extremity of each and having the two other extremities free. Upon heating the point where the two metals are joined, and connecting the two free ends by a piece of wire, an electric current is generated, the direction of which is from bismuth to antimony across the junction, and from antimony to bismuth through the connecting wire. The currents flow in the opposite direction, when the pile is cooled. From the combination of almost any other two metals, thermo-electricity may be obtained, but the current is most readily produced by that of antimony and bismuth.

The generation of thermo-electricity seems to me to be based on the same principles as the generation of electricity by contact, as occurs between the plates of copper and zinc. These principles were explained as, first, the fluctuations of temperature; and, second, the dissimilarity of molecular structure, which causes one metal to be more susceptible to heat force under one condition, and another metal under another condition. Radiation was supposed to be the motive force operating upon the insulated plates of zinc and copper, and the zinc molecules were supposed to receive more motion in this way than the copper; but when the two metals are brought in contact, the zinc molecules part with motion to the copper molecules and receive positive electricity, and the copper molecules acquire motion and negative electricity. In the thermo-electric pile the bismuth stands in the same relation to the antimony as the copper to the zinc in the case above mentioned. To the external source of heat antimony has a nearer relation and acquires and loses the heat force more readily than the bismuth, and acts, therefore, as a

medium between the two others. Hence in heating the pile the bismuth receives molecular force from the antimony and gives off caloric or positive electricity; and in cooling the pile the bismuth gives back the heat force and the electric current is reversed. But through the connecting wire, when the pile is heated, the caloric or positive electricity passes from the antimony to the bismuth, because the antimony while receiving heat force more readily at the juncture than the bismuth, loses it in turn more rapidly at the free end of the bar. The relations, therefore, of the two metal bars at their extremities would be reversed. The free ends bear the same relation to each other while the pile is heating, as the joined ends would bear when the pile is cooling. Thus I explain the production of thermo-electricity. It is the decomposition of heat fluid or double ether. The two fluids separate at the juncture of the bars, and become positive and negative electricity. As the temperature at the junction is raised, the current flows; when the temperature is stationary, it ceases; when the temperature is lowered, it flows again, but in the opposite direction.

Heat and electricity may be produced by chemical action or affinity, and by mechanical force or friction. Electricity produced in either of these ways, may be explained as in the case of that produced by the thermo-electric pile. It is the decomposition of fluid heat into currents of caloric and ether, the heat being converted into electricity as soon as formed or collected.

Let us first inquire how electricity is produced by chemical action. If two plates of metal, one of zinc and the other of copper, be immersed in water or dilute acid and then be brought in contact, either immediately or mediately by means of a conducting wire, it will be found, that as long as the two metals remain in contact, there will be a constant current of positive electricity circulating from the zinc

through the water or dilute acid to the copper, and from the copper through the point of contact or connecting wire of the two metals to the zinc; and on the other hand, that a similar constant current of negative electricity will be traversing the circuit described, in an opposite direction. The combination above described constitutes what is called a simple voltaic circle.

The chemical action which takes place between the water or acid and the metal liberates heat force; for less heat force is required to sustain matter at the same temperature in some conditions than in others. Let it be granted then, that the water and metal enter into the condition of a new compound, and that heat force is liberated. This heat force then produces expansion and the consequent absorption of double ether at the point of contact of the water and the metal, where the new compound is formed. It is found, that the zinc is more acted on by the water or acid than the copper; it therefore acquires by the chemical action more heat force than the copper, and stands in the same relation to the copper as the antimony was supposed to bear to the bismuth in the thermo-electric pile. It also bears the same relation to the copper, as it was supposed to bear when two insulated plates, one of copper and the other of zinc, are brought in contact. In both cases the zinc parts with molecular force to the copper, and the copper transmits positive electricity to the zinc. In both cases heat is converted into electricity. In one case the heat was supposed to be derived by radiation or contact with the insulating medium; in the other case the source of heat is supposed to be chemical affinity.

Heat and electricity are generated by friction. In electrization by this method, we may suppose, that the mechanical force is first converted into heat, and this again converted as readily as made into electricity by contact, as was the case

between the copper and the zinc. We know, that one kind of electricity is never produced without the other, and that they are invariably produced in equal quantities. "When one insulator is rubbed against another, one of them becomes charged with positive and the other with negative electricity; and with any given pair of materials, one invariably becomes positively electrified and the other negatively; but whereas glass rubbed with silk or flannel becomes positively electrified, when rubbed with cat's skin it becomes negatively electrified. It follows from this that the positive or negative electrization of the material does not depend absolutely on the substance of that material, but depends on some peculiar *relation* between the two substances *in contact.*" This relation may be the same as I supposed to exist between the copper and the zinc, or between the bismuth and the antimony. The heating effect produced by friction imparts more molecular motion to one non-conductor than to the other non-conductor. The latter corresponds to the copper, the former to the zinc. Resinous substances rubbed with a dry silk cloth become negative; glass similarly rubbed becomes positive. While the rubbing continues, the resinous substance is positive to the silk, and the glass is negative to the silk; but when the friction is discontinued and the bodies are separated the electrical condition of the non-conductors is found to be reversed. Hence we may infer from the explanation I have already given of electricity, that the molecules of the resinous substances correspond to those of copper or bismuth, and acquire motion less rapidly than the molecules of the silk; and that the silk molecules on the other hand correspond to the molecules of the zinc or antimony. Hence in contact the positive electricity flows from the resinous substance to the silk, just as in the thermo-electric pile it is found to flow across the junction from the bismuth to the antimony, and the negative electricity flows

in the opposite direction from the silk to the resinous substance. But when the resinous substance and silk are separated after having been rubbed together, the resinous substance will be negative, and the silk rubber will be positive, as was the case with the copper and the zinc after being brought in contact and separated. The molecules of glass stand in the opposite relation to the molecules of silk, or as the zinc to the copper. The glass acquires molecular motion by friction more rapidly than the silk, and, therefore, absorbs caloric and parts with ether. Thus the glass and resinous substance are oppositely electrified, because their molecules stand in opposite relations to the molecules of silk in regard to the quality of receiving motion from friction.

A hot body rubbed by a cold one identical with it in chemical composition becomes negatively electrified. Again, when two pieces of glass are rubbed so that all the parts of one pass over one part of the other, the former is positive and the latter negative. It is evident that by rubbing two pieces of glass together in this manner one would become more heated than the other; so that I will consider this as only another example of a hot body rubbed by a cold. To make this example of electrization similar to the others, we must suppose that the molecules of the cold body acquire motion by the friction more rapidly than the molecules of the hot body, and that they part with some of the motion thus acquired to the hot body; that this communication of motion from the cold to the hot body is not such as to increase the temperature of the hot body, but such only as to retard the cooling of the hot body in contact with the cold body. If this be true the electrization effected in this way falls under the same law of relation as that supposed to exist between the zinc and the copper, the antimony and the bismuth, the glass and the resin.

I have now defined electricity, as I described heat, as the

joint product of fluid and force. I will use the term *conduction* to denote the passage of the fluids, and the term *induction* to denote the passage of electric force. Radiation is the passage of force by a vibratory motion through the interstellar medium; induction takes place by the intervention of ponderable matter. To illustrate by the insulated plates of copper and zinc, I supposed them both to be heated by radiation, and that the zinc molecules received more molecular motion in the same time by radiation, than the copper, and that drawing caloric from the same source as the copper, and being at the same time a worse conductor, it had an inadequate supply. When, then, it came in contact with the copper, it parted with molecular motion by *induction* and received caloric or positive electricity by *conduction*. An electric *discharge* is the passage both of fluid and force.

"Attenuated gases," says Grove, "may be regarded in one sense as non-conductors, in another as conductors; thus if gold leaves be made to diverge by electrical repulsion, in air at ordinary pressure, they in a short time collapse, while in highly rarified air, or what is commonly termed a vacuum, they remain divergent for days; and yet electricity of a certain degree of tension passes readily across attenuated air and with difficulty across air of ordinary density." This passage from Grove's essay on "Correlation of Physical Forces," contains facts, which appear to me to be unexplainable upon the assumption that electricity consists of fluid alone or force alone. But they may be explained upon the assumption that electrical phenomena are the joint result of fluid and force. Upon this assumption the facts above mentioned may be thus accounted for: discharge never takes place without induction. Where the two electrified bodies are separated by a *vacuum* no induction can occur; for the passage of force by induction requires the intervention of ponderable matter, and consequently there is

no discharge. Where, on the other hand, neither of the electrified bodies is placed within the *vacuum*, they have a channel of communication between them for the electric force through the intervention of ponderable matter, which may be the air surrounding them. Through this medium then the electric force may pass by induction, while the electric fluid passes without obstruction through the *vacuum*.

"It is frequently said, that positive electricity attracts negative electricity, but that positive repels positive, and negative repels negative. We have stated, that electrified bodies do present attractions and repulsions of this kind, and by a slight extension of language the electricity itself may be spoken of as attracting or repelling; but there is a further phenomenon called *statical induction*, which does appear more distinctly to represent an attraction or repulsion of electricity, besides the attraction and repulsion of the bodies charged with electricity. If a body, A, charged with positive electricity, be brought into the neighborhood of a body B, at a different potential it will attract negative electricity to that end of the body B, which is near it, and repel positive electricity to the remoter portions of B. If the body B be insulated, it neither loses nor gains electricity, but its ends are competent to produce electrical phenomena of opposite kinds. Separating the two ends we may retain each charged with its positive and negative electricity. Or if we connect the further end of B with the Earth even for a moment, the positive electricity will be driven off to the Earth, and a permanent negative charge will then be retained on B. Otherwise when A is removed the positive and negative electricity on B recombine and exactly neutralize one another. By induction, as in the case of electricity obtained by friction, precisely equal quantities of positive and negative electricities are simultaneously produced." I shall attempt to explain this phenomenon somewhat in the manner

in which I explained the electrization of the copper and zinc when brought in contact and afterwards separated. The body A, which is positively electrified, has less molecular motion than the body B, but a denser atmosphere of caloric around its molecules. A then corresponds to the insulated plate of copper, and B to the insulated plate of zinc.

As soon, however, as the two bodies are brought near each other, the former acquires and the latter loses molecular motion upon their contiguous surfaces by induction. Perhaps the motion does not actually pass, unless a discharge of positive electricity passes, but that there exists only a tendency to pass, the actual passage of force being prevented by the insulator, which prevents the passage of the fluid electricity. The tendency to pass increases as the bodies are approached, and diminishes as the bodies are separated. But reasoning as if the passage of the force actually occurred, A will have more molecular force on its side next to B, than on the side opposite; B, on the contrary, will have more on the side farthest from A than on the side next to A. Thus A acquires motion or a tendency to motion by induction from B, just as the piece of copper was supposed to acquire molecular force by contact with the zinc; and when again A is moved out of proximity with B, the two bodies are affected as the copper and zinc after separation; for A loses the tendency to acquire force by induction, and B the tendency to impart. The insulator prevents the positive electricity from passing from A to B, and consequently the negative from passing in the opposite direction. But at the same time, owing to increased motion in the molecules of A and diminished motion in the molecules of B at their contiguous or adjacent sides, the surface of A next to B will have a tendency to discharge positive electricity, while in proximity with B, and the corresponding surface of B will

have a tendency to discharge negative electricity while in proximity with A. Hence there are *two modes of insulation:* first, by a *vacuum*, which prevents the passage of force by induction; second, by a non-conductor, which prevents the passage of fluid electricity. Let us suppose a third body, C, to be so placed, that B shall be in a position between A and C; B will induce in C a condition similar to that induced in B by A. For if there is a tendency in A to abstract motion from B so as to reduce its molecular force to a condition below that of surrounding bodies, there must be a tendency in B to abstract molecular force from C to an equal amount with that which it imparts to A. Hence B acts as a conductor between A and C, when all three bodies are brought in contact, and the fluids and force pass simultaneously.

Thus far I have considered induction, only as it appears in static electricity, and which is called electrostatic induction; induction also takes place between conductors through which currents are passing and neighboring conductors, and is then designated electromagnetic induction. "This induction is the unfailing accompaniment of the beginning or increase and termination or decrease of a current, for there are always conductors somewhere near in which the induced currents flow. The induced currents diminish for the time being the strength of the inducing current, and thus we see, that neighboring bodies change the rate, at which a beginning or ceasing current comes to its permanent condition. If the whole or a large part of a circuit of small resistance is very near the inducing current and so disposed that the induction tends to occur throughout in one direction, the induced current will be considerable, and its reaction on the inducing current will also be great, shortening the time it requires to reach the permanent condition. If the circuit, in which the induced current flows, is on the contrary, far removed from the inducing current,

or only exposed to induction for a small part of its length, or so placed that the current tends to flow in opposite directions at different parts of the circuit, or has a great resistance, then the induced current will be small and its reaction on the inducing current will also be small. The inducing current produces an electromotive force in the circuit conveying the induced current, and we may say that the induced current is due to the induced electromotive force."

Let us suppose a current of positive electricity to be passing through a circuit A, B, C, etc., in the direction of the alphabet. This current will induce in a neighboring conductor, *a*, *b*, *c*, a current of positive electricity which will flow against the alphabet. Electricity consists, as I have remarked, not only of the passage of fluids through the conductor, which is called conduction, but in the passage of electromotive force, which I have called induction. The conduction or passage of the fluids is caused by the induction of the force. This I have already explained; and we have only now to suppose, that the insulated bodies A, B, and C, which were supposed to be electrified, the first with positive electricity by friction, and the second and third by induction, have been brought in contact and form a conductor A, B, C, through which a current of positive electricity passes from A to C. According, then, to the explanation already given, the caloric or positive electricity flows in the direction of the alphabet through the conductor, and the electromotive force moves against the alphabet. The fluid passes from A to B and from B to C, only when these bodies are in contact, forming a chain or channel, which is called a conductor. The force, however, was supposed to pass between them by induction, even while they were insulated. Now, as we supposed, that the electromotive force could pass and did pass from B to A and from C to B

by induction, while they were separated by insulators, so we may suppose that the electromotive force may pass from the conductor A, B, C, D, etc., by induction to the neighboring conductor *a, b, c, d,* etc.

It is found by experiment, that when the conductors approach, or when the current in A, B, C, D, commences or is increased, the induced current in *a, b, c, d,* will move opposite or against the alphabet; but that when the inducing current in A, B, C, D, is removed from the conductor *a, b, c, d,* or is diminished or ceases, the induced current moves with the alphabet or in the same direction as the inducing current. In the former case when the inducing current is increasing, the electromotive force in the induced current moves from *a* to *b* and from *b* to *c,* and so on in the direction of the alphabet; but in the latter case, when the inducing current is diminishing, the electromotive force in the induced current moves against the alphabet. We are now to inquire, why the electromotive force in A, B, C, D, induces an electromotive force in *a, b, c, d,* which moves in one condition of the current in the same direction as the electromotive force in A, B, C, D, and in another condition of the inducing current in the opposite direction.

For a current to flow from A to D, A must be at a higher potential or have more positive electricity; and according to our theory there must be more electromotive force at D than at A. Now if we compare the conductors A, B, C, D, and *a, b, c, d,* which are supposed to be side by side, while a current is passing through A, B, C, D, in the direction of the alphabet, we shall find that there is more electromotive force at D than at *d,* and less at A than at *a,* while the current is increasing in A, B, C, D. Hence the conductor A, B, C, D, will induce electromotive force from D into the conductor *a, b, c, d,* at the point *d,* which will begin to pass from *d* to *a,* and the point *a* will induce electromotive force into A.

Thus the presence of the conductor *a, b, c, d*, in the neighborhood of the conductor A, B, C, D, will diminish the flow of electromotive force from D to A, through the conductor A, B, C, D, and will cause a passage of electromotive force from *d* to *a* in the conductor *a, b, c, d*. Hence we see, since it is the flow of the electromotive force from D to A, which produces the flow of the fluid electricity from A to D, that the current of A, B, C, D, must be retarded by the induction of electromotive force in *a, b, c, d*, at the point *d* from D, and in A, B, C, D, at A from *a*. This induction will take place as long as there is a dissimilarity in the condition of the two conductors. As long as the inducing current increases and the force of electricity grows up in D more rapidly than in A, the current A, B, C, D, will be resisted and retarded, and a current will be induced in *a, b, c, d*, in an opposite direction to the inducing current. As long as the ratio of the electromotive force at D to that at A is greater than that of *d* to *a*, the point D will continue to induce force in *d*, and the point *a* will induce force in A, and the inducing and induced currents will flow in opposite directions. But as soon as this proportion is reversed, so that the ratio of *d* to *a* is greater than the ratio of D to A, which will occur when the inducing current decreases, the flow of the electromotive force in *a, b, c, d*, will also be reversed, so that A will induce electromotive force in *a*, and *d* will induce it in D. Hence the neighboring conductor *a, b, c, d*, serves as a reservoir in which the electromotive force of A, B, C, D, is stored. The flow of the inducing and induced currents will then be in the same direction, and the diminution of the inducing current is retarded. Thus we see, that the effect of the conductor *a, b, c, d*, upon the conductor A, B, C, D, is to delay change in its electrical condition, since they react upon each other, having a tendency to induce the same relations between the extremities of the one, as subsists between the

extremities of the other. In the conductor *a, b, c, d,* I have supposed the positive electricity to flow in the same direction as the electromotive force; for the fluid does not leave the conductor, but the induced electromotive force merely affects its distribution, the fluid accumulating where the motion is diminished, and being rarified where the motion is increased. Otherwise the electricity would be converted into heat. But the conductor A, B, C, D, serves merely as a conductor between two electrified bodies, and the fluid and force pass in opposite directions to restore the electrical equilibrium. The approach of the circuit A, B, C, D, to the conductor *a, b, c, d,* has the same effect as the increase of the inducing current, and the removal of the circuit as the diminution of the current.

But besides the effects, which the approach and removal of the circuits A, B, C, D and *a, b, c, d* have on the inducing and the induced currents, the phenomenon presents another feature, which is the *resistance* of the currents to the approach or removal of the circuits. Thus when we attempt to bring the circuits nearer to each other, we induce currents which move in opposite directions, and currents moving in opposite directions repel each other; and when we remove the circuits farther apart, we induce currents which move in the same direction, and currents, which move in the same direction, attract one another. The cause of the currents moving in the same direction under one condition, and in opposite directions under a change of this condition has been explained; we are now to explain the action of the currents on the movement of the conductors, or why it is that currents moving in the same direction attract, and moving in opposite directions repel one another. These attractions and repulsions are wholly distinct from the attractions and repulsions between charges of static electricity. For in these the positive body or the positive pole

attracts the negative and repels the positive, so that likes repel likes and attract unlikes. But in the attractions and repulsions between currents of electricity, the positive parts of a circuit attract the positive parts of an adjacent circuit, and the negative attract negative, or else the negative and positive repel each other.

Two parallel wires in which electric currents flow in the same direction attract one another; and two parallel wires in which electric currents flow in the opposite directions repel one another. It is usual to describe these phenomena as if there were an attraction between the electricity of one circuit and that of another. It is not likely, however, that the opposite electricities, which attract each other in the same conductor, should repel each other between neighboring conductors. The most probable view to take is, that the phenomena are produced by the peculiar conditions in which the molecules of the conductor are thrown by the passage of the electricity, so that in one condition the impulsion of the molecules of one conductor for those of the other is increased, and in the other condition the property is reversed. Thus the two conductors stand in the same relation to each other as two molecules, which in the position of parallelism, rotating in opposite directions, repel one another and constitute the gaseous state of bodies, and rotating in the same direction attract one another and constitute the solid form. These properties of electric currents, discovered by Ampere, seem to have suggested the three positions of molecules in the three forms of matter.

I have explained how in some positions of molecules, the same amount of rotary force may produce more repulsion, than in others. Now if a current of electricity passing through a wire would polarize all its molecules and cause them to rotate at right angles to the direction of the current as I have supposed, then the three positions of the circuits

corresponding to the three positions of molecules in the solid, liquid and gaseous forms of matter, would produce analogous effects. For any two conductors can be so arranged as to place the molecules of one in any of these three positions with regard to the molecules of the other; and although no two molecules at so great distance apart as the two wires would produce any perceptable effect the one upon the other, yet in masses they might; so that electrical repulsion bears the same relation to gravity, being action between masses, as heat bears to the cohesion of molecules.

The readiness with which molecules of masses are polarized by the electric current in one direction may be that, which constitutes a good conductor. Hence we may imagine why solids, whose molecules rotate in the same direction, or nearly in the same direction, are generally good conductors. While liquids may be classed as imperfect conductors; and gasses, in their ordinary state of density are non-conductors.

CHAPTER VI.

ON MAGNETISM.

EVERY current of electricity through a conductor is apparently accompanied by two modes of motion, one directly through the conductor, and the other, termed *magnetism*, in circles or spirals around it. Magnetic currents, as this spiral motion may be designated, are probably produced in the molecular atmospheres of the conductor by the rotation of the molecules. It is these which effect the attractions and repulsions between conductors, which I have already described, causing conductors through which currents are passing in the same direction to attract, and conductors through which currents are passing in opposite directions to repel one another; from which it happens, that two conductors, through which electric currents are passing tend to place themselves in parallel positions. This I have supposed to be due to the polarization of molecules, which are made to rotate at right angles to the direction of the currents. Hence an electric current is found to shorten a conductor as well as to make it more tenacious; for the attractions of molecules for one another is strongest between their poles.

But when a magnet is brought near a wire, through which a current of electricity passes, it is always deflected at right angles to the current. If now we attribute the deflection of the magnet and the parallelism of the two conductors to molecular forces, we shall have to conclude, that the molecules of the deflected magnet are polarized at right angles to the line of polarization of the molecules of the conductor. Hence the magnetization of a bar of iron is said to have an effect upon the texture of the metal unlike that produced by

the current of electricity upon the conductor. For the wire is made shorter and more tenacious by the passage of the electricity; but the bar is lengthened by being magnetized and is rendered more brittle.

In a conductor, through which a current is passing, the arrangement of the molecules may be compared to parallel rows of beads strung on straight wires; the structure of a magnet may be compared to beads strung on a helix. If the above conductor be placed by the side of another conductor, it will induce a molecule arrangement in this conductor similar to its own. This sort of action of the electromotive force is essential to the induction of currents. Magnetization is produced by the induction of a current into a bar of iron or steel by winding the conductor, through which the current is passed, around the bar to be magnetized. The molecular arrangement of the bar then becomes like that of the coil of wire in which it is enclosed. Thus a similarity of structure gives rise to that similarity of action which subsists between a magnet and a coil, when the latter has a current passing through it. The opposite ends of the coil have the same properties as the opposite poles of a magnet, and if a coil be brought into the neighborhood of an electric current it will be deflected like a magnet.

Let us examine then into the properties of the coil, with an electric current passing through it. The coil acts like a magnet and is capable of inducing magnetism. From what I have already said on the subject of electro-magnetic induction, we may readily understand how a current would be induced into an unbroken circuit moved into the neighborhood of either pole of the coil, and when electricity is induced, the magnetic energies always accompany. The unbroken circuit may be either a bar of soft iron or it may be another coil. If we approach the solenoid, for such the inducing coil may be called, to the circuit or increase the

current in the solenoid, a current is induced in the circuit, which moves oppositely to that in the solenoid. The induced current magnetizes the conductor, through which it circulates; and as long as it moves in an opposite direction to the inducing current the induced magnetism will be opposite to that of the solenoid, and the north pole of the solenoid will induce a north pole in the circuit, and a south pole will induce a south pole. The circuit and solenoid then repel each other. But if we withdraw the solenoid or diminish the inducing current, a current is induced in the circuit moving in the same direction as the inducing current. So long as the currents move in the same direction a north pole will induce a south pole, and a south pole a north pole.

If we substitute for the circuit a bar of soft iron it will be magnetized and demagnetized in the same manner as a ring or coil. If it be a steel bar it may be permanently magnetized. Now a permanent magnet differs in some respects from a solenoid. In the first place, it has not currents of electricity circulating through it, but it has magnetic currents or magnetism, which is due to molecular forces. Nevertheless it is like the solenoid in inducing both electricity and magnetism; for induction takes place between the molecules of insulated conductors, and not between the currents of electricity which pass through them. It is more of a molecular, than an electrical phenomenon. We may suppose a bar of steel to have been magnetized by the solenoid. We may then take the steel magnet, and substituting it for the solenoid, produce the same results upon a neighboring circuit. We may with the steel magnet, which has no electric currents circulating through it, induce electric currents and magnetism in the circuit. If we approach the circuit to the magnet, we induce a current of electricity in the circuit and a magnetism which produces repulsion. If

we withdraw the circuit, we reverse the current and induce a magnetism which attracts. Varying this process a little, magnets may be made to induce magnetism, without inducing electric currents. We place the opposite poles of two equally strong magnets in the center of a bar to be magnetized, and by drawing them simultaneously away from the center to the two ends, produce an effect corresponding to the withdrawal of the circuit from the magnet. The same principles apply to the following method of magnetizing a horse-shoe bar: Place the ends of the bar in contact with the poles of a horse-shoe magnet, then draw a bar of soft iron over the horse-shoe bar away from the poles of the magnet. This has the same effect as withdrawing the circuit, in the experiments mentioned above.

It has been said, that currents moving in the same directions attract one another, but moving in opposite directions repel. The principles, upon which these phenomena were explained, apply to the polar attractions and repulsions of solenoids and magnets. If two solenoids be applied with the north pole of the one to the north pole of the other, or with south pole to south pole, the currents oppose and produce repulsion by giving to the molecules of the one that relative position to the molecules of the other, which according to hypothesis constitutes the gaseous form of matter. But if the north pole of one is applied to the south pole of the other, the currents move in the same direction and the molecules take the position for the solid form. If a solenoid is placed parallel with another solenoid, so that the poles of one are applied to the opposite poles of the other they attract, because the magnetic currents produced by the rotation of the molecules move along the surface of the solenoids in opposite directions. But if the position of the solenoids is reversed, so that the magnetic currents move in the same direction, the solenoids are repelled. For moving

in the same direction the magnetic currents assist each other; but moving in opposite directions, the effect is neutralized and the caloric atmospheres of the molecules are made more dense. For I will again repeat, that the attractions and repulsions between magnets, and the attractions and repulsions between conductors, through which electric currents are passing, are all duê to the same causes, and are of the same nature as the attractions and repulsions between molecules in constituting the solid, liquid and gaseous forms of matter.

We may describe or distinguish the two unlike or opposite poles of a magnet as follows: The positive pole is that, which tends to the North pole of the Earth, and the negative pole is that which is attracted to the South pole of the Earth. Hence regarding the Earth as a magnet, its North pole must be negative and its South pole positive. If the magnetic energies move along the surface of the Earth from North to South, then the magnetic energies of the needle which points to the North must move along the surface of the magnet from its negative to its positive pole; for it is necessary, as I have explained, for the magnetic energies or currents to move in opposite directions to produce attraction. The magnetism of the Earth has been supposed to be due to electric currents generated by the unequal heating of the Earth by the rays of the Sun and passing along the surface of the Earth from East to West. Now if we suppose the magnetic currents to move along the Earth's surface from North to South, we readily understand how the molecules on the Earth's surface are rotated by the electric currents from East to West in order to produce magnetism. We may illustrate the motions of these molecules by imagining them to be strung on a wire stretched from North to South and rotating in the same direction as the Earth on its axis, or against the motion of

the Sun. Then let the north end of the wire be imagined to be carried around to the East and the South end to the West. It is plain that this motion of the molecules would tend to drive their caloric atmospheres in a southerly direction.

Now if we suppose a magnet or solenoid to be directed by the Earth's magnetism with its north or positive pole to the north pole of the earth its magnetic currents must move opposite to those of the Earth. Therefore the molecules at the top of the solenoid move in an opposite direction to those upon the surface of the earth, and the molecules at the bottom of the solenoid move in the same direction as those of the Earth. Now if we suppose that an electric current always polarizes the molecules of the circuit in the same direction from right to left as the thermo-electric currents flowing through the Earth were supposed to do, then we must suppose that the electric currents, which produce the magnetism of the solenoid directed as above, must move around the solenoid from right to left over it and in the opposite direction under it; so that over those parts of the Earth and solenoid which are adjacent the currents of electricity move in the same direction. But it would make no difference at which end of the solenoid the electric current enters, provided it flows across the solenoid in the same direction. But to make the current flow in the two cases in the same direction across the solenoid the wire of the solenoid would have to be coiled in opposite directions. If a current of electricity moved around the coil as the hands of a watch, the face of the watch will represent the south pole and the back of the watch the north pole of the solenoid or magnet, whether the current commence at the back or enter from the front.

In all these cases the magnet acts as the solenoid, and comports with the hypothesis that there is a sameness in

their molecular structure. Magnets and solenoids differ, however, in one remarkable respect, to which I will now advert. The coil induces a magnetism in a bar of soft iron, placed in the coil, unlike that magnetism induced by a hollow magnet. The bar serves only to strengthen the magnetism of the coil, which becomes saturated when it has reached a certain point. But if a bar of soft iron is placed within a hollow magnet, the north pole of the magnet will induce a south pole in the bar, and the south pole of the magnet will induce a north pole in the bar. Thus the coil and the hollow magnet produce opposite results. If, instead of a bar of soft iron, a bar of steel be inserted in the coil, it is found that the magnetization can go on only to a certain point, and that the steel is sooner saturated than the soft iron, but retains its magnetism longer. Again there are some bodies which instead of being attracted by the poles of a magnet, are repelled and tend to place themselves across it at right angles to its axis. All these facts tend to show that, while the internal structure of magnets agree in certain respects, there are, on the other hand, certain other respects in which they differ not only from solenoids but disagree among themselves.

In order to explain the difference above stated in the actions of solenoids and magnets, it has been said that a hollow magnet acts not as a single solenoid, but as if it were composed of an immense number of little solenoids arranged together side by side. If it be a bar of soft iron, which is magnetized, the little solenoids are placed in parallelism by the electric current, but move out of parallelism when the current ceases. A bar of hard iron or steel contains not so many of these solenoids as a bar of soft iron of the same weight, nor are they so free to move; but after they have been arranged in parallel rows by the action of magnetic energies, owing to the entanglement of other matter with

these solenoids, they retain their positions longer in the steel, than in the soft iron. But the fact that bodies become saturated with magnetism, is a proof, that magnetism is due to molecular forces. For after all the solenoids, which a bar of soft iron or a bar of steel contains, have been arranged in parallelism, the bar of iron or steel cannot be made more magnetic by increasing the current of electricity in the coil.

The Earth, which is considered to be a vast magnet, differs from the steel magnet as the steel from the bar of soft iron; that is to say, it contains not so many solenoids in proportion to its magnitude. The Earth is not a permanent magnet, nor is it saturated with magnetism, but it is subject to magnetic storms, as if the coil or solenoid, as it were, which engirds it, were sometimes twisted out of position, so that the electric currents, whose general direction is from east to west, are shifted from their course and vary in direction as well as in strength and intensity. The varying temperature of the Earth's surface is one of the causes, which affect the passage of these currents. For the magnetism of the Earth is found to undergo annual variations from winter to summer and from summer to winter again, and in like manner with the fluctuations of temperature it is subject to daily variations. That these currents should circulate around the Earth, instead of penetrating and passing through it, may be due to the fact, that the Earth increases in temperature as we proceed downwards. It is even supposed by some, that the inhabited Earth is but a comparatively thin crust resting upon a molten and liquid mass. Hence the outer coating of the Earth may be in the nature of a circuit, insulated by the atmosphere on the one side and by the intensely heated substances of the interior on the other side. So that be the cause what it may, by which electric currents are generated in the Earth, they seek the best conductors and flow around it, instead of penetrating to its interior, or flying off into the regions of space.

CHAPTER VII.

ON THE GENERAL DISTURBANCE OF ELECTRICAL EQUILIBRIUM BY THE MOVEMENTS OF THE HEAVENLY BODIES.

According to the double ether hypothesis, all space is conceived to be filled with two fluids, *ether* and *caloric,* which mix with each other and vary in density with the mass and distance of bodies which they surround. The union of these and their passage in the same direction constitutes fluid heat, and their separation and passage in opposite directions produce electrical phenomena. I have explained already, how the movements of atoms and molecules affect the distribution of these fluids both in regard to heat and electricity. I now propose to explain the effects produced upon them by the movements of the Earth and celestial bodies, so as to account for the magnetism of the Earth, the luminosity of the Sun and Stars and the singular disturbance of the matter of Comets, as they approach or recede from the Sun.

First let us inquire into the nature of the source of the Earth's magnetism. This is sometimes supposed to be due to electric currents generated by the unequal heating of the Earth by the rays of the Sun and passing along the surface of the Earth from East to West. It is plain, that this hypothesis cannot apply to the magnetism of the Sun, if the Sun, as some suppose, be a magnet. The hypothesis which I propose, applies to all the heavenly bodies, which have atmospheres like the Earth and motions like it upon their axis and in elliptical orbits. For the present I will consider only the effect of the Earth's motions around the Sun, and will explain how this motion disturbs the equilib-

rium between the ether and caloric, and how the flow of these fluids to restore equilibrium produces the magnetism of the Earth.

According to the hypothesis of gravity, which I have presented in the aforegoing pages, I have represented it to be the property of caloric, owing to the pressure of ether, to be densest at the center of a gravitating body and to decrease outwardly in density, in the manner of the atmosphere, which surrounds the Earth. The movement of the Earth through space, therefore, would have a tendency to carry it away from that part where the caloric is densest, or out of the caloric globe; and we must see, that the pressure of the ether would cause the caloric to follow the Earth. The Earth and caloric would not move in virtue of the same principle. The force which moves the Earth is the property of inertia in its mass; the force, which moves the caloric globe, after the Earth, would be the extraneous pressure of ether. They would not move together. Hence, on account of the motion, which tends to carry the Earth away from the caloric, a certain part of the Earth would always be positive or have a superabundance of caloric, or positive electricity, and another part would be negative. The place from which the Earth is moving must be positive, and the place to which it is moving, negative. We may say, therefore, that the Earth's surface is at a different potential in one part from what it is in another; and that it is at a higher potential on that side from which it moves, than on the side opposite.

If the orbital motion of the Earth were always uniform, and the Earth had no axial revolution, the difference of potential produced by its projection could not generate currents of electricity; but the same relation would exist between the positive and negative points of the Earth, as is sometimes induced by a constant and uniform current of electricity in

the two opposite points of a broken circuit. The analogy goes farther. As long as the inducing current remains constant and uniform, the difference of potential in the opposite points of the broken circuit, remains constant and no current is induced; but if the strength of the inducing current increases or diminishes, the difference of potential increases or diminishes in proportion and a current of electricity is induced. When the inducing current increases, the induced current flows from the negative to the positive point in the broken circuit, and in the reverse direction, when the inducing current is diminished. So it would be with the positive and negative points above referred to, in the surface of the Earth, supposing it to have no motion on its axis, but only a rectilineal projection, or the motion in its orbit. We will say that this projection is from West to East; we may, therefore, regard the western extremity of the Earth as the positive point and the eastern extremity as the negative point. The Earth's motion in its orbit is not uniform; but varies with every day in the year. During one half of the year, as it approaches its perihelion, its motion is accelerated; during the other half its motion is retarded. Now let us inquire what would be the effect of the Earth's axial or diurnal motion upon its electrical potential.

We know that the Earth moves on its axis from West to East, which causes the Sun to appear to move from East to West. If we suppose the alphabet A, B, C, D, etc., to represent the motion of the Earth on its axis from West to East, then the Sun will apparently move against the alphabet, or in the direction D, C, B, A; and we may now demonstrate, that a current of positive electricity would flow around the Earth in the same direction as the apparent motion of the Sun. We must bear in mind, that although the ether or negative electricity flows with the utmost freedom through the pores of ponderable matter, caloric or positive electricity

does not, and the amount of resistance, which it encounters in its passage, is what constitutes or distinguishes a good or bad conductor. Hence the surface of the Earth being brought by its axial rotation to that point, where the potential is highest, would collect positive electricity, and would carry it around in the direction A, B, C, D; until the tension of the electricity at C or D would be sufficient to overcome the resistance of the conductor and cause the current to flow from C or D to A, or against the alphabet. On the contrary, the opposite point on the Earth's surface charged with negative electricity and moving in the direction A, B, C, D would attract the opposite electricity. Hence there would be a continuous flow of electricity from East to West.

The resistance referred to above might be greater or less according to the temperature of the conductor. Hence fluctuations of temperature may have much to do in occasioning those electrical storms, which sometimes result from difference of potential of some localities on the Earth's surface and affect telegraphic communication. A higher temperature would increase the resistance of the solid substances of the Earth, and would diminish that of the atmosphere. Hence upon the temperature might depend, whether the surface of the Earth or the atmosphere would carry the electricity back to C or to D. If the surface of the Earth, heated, would carry the fluid to D; when cooled it would carry the electric fluid only to C. The point on the Earth's surface, therefore, corresponding to D would have a higher potential than the point C, and being connected by a telegraph wire or any other good conductor a current of electricity would flow between them.

These currents flowing along the Earth's surface from East to West would produce magnetism in the same manner as the thermo-electric currents generated by the heat of the Sun. They would flow chiefly through the Earth's surface

and not through the atmosphere. For without regard to temperature, some bodies admit the passage of caloric more readily than others; hence good conductors in passing the positive point, would collect more, but retain less positive electricity than more imperfect conductors. The atmosphere for this reason would collect less caloric than the Earth at the positive point, but it would retain it longer. Hence the flow of current through the atmosphere might not be sufficient to affect the Earth's magnetism to a very great extent.

I have thus far considered only the effect of the projection of the Earth upon its potential, without taking into consideration the existence and action of other bodies as the Sun and Moon. The gravity of these bodies is perhaps a far more potent agent in producing the points of high and low potential and destroying electrical equilibrium of the Earth's surface, than the projection of the Earth. In whatever place the caloric would be densest would be the point of high potential, and where the caloric is least dense would be the point of low potential. Now according to the theory which I have proposed for the explanation of the gravitating force, the caloric is supposed to decrease in density as we proceed from dense bodies outwardly, and when two bodies gravitate to one another the caloric grows in density between them. Hence the Earth's high potential point would be on the side next to the Sun or Moon, as on this side the caloric is densest, and its low potential point would be the side opposite to the Sun or Moon. I suppose the theory of gravity, which I have proposed in the preceding pages, to be well enough understood to make this clear. Hence the Earth might have two points of high potential on its surface and two points of low potential, according to the positions of the Sun and Moon. For each of these bodies would have a tendency to raise a point of high potential and a point of low potential; but when

they happen to be on the same side of the Earth the two points of high potential would coincide, and be on the side of the Earth next to these bodies, and the two points of low potential would likewise coincide and be on the opposite side of the Earth. The effect, however, in producing electric currents would probably be the same, whether there be one or two points of high or low potential; at least so far as their direction is concerned, this being due to the rotation of the Earth on its axis. The Earth's projection or the Sun's gravitation disturbs the electrical equilibrium on the Earth's surface, and its revolution on its axis produces the flow of electricity from East to West. I have said, that the difference of potential between the positive and negative points would be increased with an increase of the Earth's projection, and *vice versa*. I was then considering the effect of this motion upon the potentials, independently of the Sun's attraction. Gravity would have the effect of reversing this result; for when the Earth moves away from the Sun, its motion and gravity act together in raising the Earth's potential on the side next to the Sun; but when the Earth approaches the Sun, the Earth's motion and gravity counteract each other by raising potential on opposite sides. Hence the strength of the Earth's currents and the intensity of its magnetism, depending on a varying potential, must be greatest during the passage of our planet from its winter to its summer solstice and least upon its return.

So far, I have considered only that cause which affects the electrical equilibrium of the Earth's surface and causes one locality to be at a higher potential than another. I will now consider another effect of the Earth's motion of no less importance perhaps than that which I have considered in the preceding pages. It is that effect of its motions, which causes it to be at one time of a higher potential, than the

regions of space surrounding it, and at another time at a lower potential. I wish to show, why it is, that the upper regions of the Earth's atmosphere are sometimes positive and sometimes negative, and at what seasons we should expect this difference of electrical state to occur. For besides the electrical disturbance, which takes place upon the surface of the Earth and produces magnetism, there is an electrical disturbance produced by a similar cause in the upper regions of the Earth's atmosphere, which probably gives rise to the phenomena of the aurora borealis. This disturbance is due in part to the Earth's motions and partly to the non-conducting properties of the atmosphere. For if caloric passed as readily through all bodies as ether and through all bodies alike, no electrical disturbance would ever take place. What I mean by an electrical disturbance is a disturbance of that condition of density, which the caloric is supposed to assume under the pressure of ether around all bodies; for the pressure of the ether causes the caloric to assume a certain condition, and if this condition is disturbed or altered by any foreign cause, as the motions or positions of the heavenly bodies, it will return to its normal condition again, as soon as the resistance is overcome. The condition of the caloric or positive electricity around the Earth would vary with its distance from the Sun. For the density of the caloric would diminish around the Earth, as the Earth approached the Sun, and it would increase as the Earth receded again. (For the gravity of bodies to the Earth is diminished by the attraction of the Sun; on this principle the rise and fall of the tides are explained.) But for a given distance, its density would be always the same. This condition of the caloric I have explained under the head of gravity. I will now explain how the motions of the Earth may disturb it.

First, then, let us suppose, that the caloric is in that con-

dition of density around the Earth, which it would assume if no change took place in the Earth's distance from the Sun. We will then say, that its caloric atmosphere is in electrical equilibrium. This would occur if the Earth's orbit were a circle. But none of the planets move in perfect circles; and the comets, in which the electrical disturbance would be greatest, move around the Sun in orbits, which are very eccentric. When the earth moves from its perihelion to its aphelion, the density of the caloric has a tendency to increase around the Earth, and therefore the caloric passes to the Earth from the regions of space, or we will say from the upper regions of the air. But the flow of the caloric to the Earth will be resisted by the non-conducting properties of the aerial atmosphere surrounding it. The atmosphere, or upper regions, will then be positive and the Earth negative during the season of the year when the Earth passes from its winter to its summer solstice. A vast amount of electricity might thus accumulate in the upper regions, where the air is very attenuate and a better conductor, than it is in the lower regions near the Earth's surface. But when the Earth leaves its aphelion and approaches the Sun, its caloric atmosphere will have a tendency to decrease in density, until the Earth arrives at its perihelion. The Earth is now positive and space negative, and the current has a tendency to flow from the positive to the negative body. The upper regions of the air being a good conductor are soon discharged of their positive electricity; but the lower regions of the atmosphere, where the air is dense, resists the flow of electricity from the Earth. The electrical conditions of the Earth and its aerial atmosphere therefore are reversed at the opposite seasons of the year, when the Earth approaches and recedes from the Sun. The passage of electricity due to this change of electrical condition here pointed out may produce some of those luminous phenomena,

known as the aurora borealis, in the Earth's atmosphere, as well as the luminous clouds of some other planets, but especially that brilliant appearance of comets.

Now the electrical phenomena, which are produced, must depend on two causes; first, the tension of the electromotive force, which is greater or less according to the eccentricity of the planet's orbit; second, the resistance of the air, which depends upon its magnitude and density. We should, therefore, expect to find a more brilliant electrical display in the case of a comet, than in the case of a planet. An orbit nearly circular and an extremely small and rare atmosphere may be the cause of the faint luminosity of the planet Jupiter, notwithstanding the greatness of his mass and motions; for we know, that the voltaic arc is much more brilliant, when the current is passed through air of ordinary density, than when passed through a partial *vacuum*. On the other hand, the comets are self-luminous bodies, although extremely small. But their motions are vast; their atmospheres are extensive; and their orbits are very eccentric. All these properties of comets here enumerated tend to produce change in their electrical conditions, like those which I explained as produced in the Earth by its varying motion and elliptic orbit.

Let us consider again what this change is, and I think we will be able to form some idea of the cause of the comet's luminosity, as well as of the repulsion of luminous matter from the body of the comet as it approaches the Sun, and we will be able to see, too, why the luminous matter is repelled from the comet in a particular direction, that opposite the Sun. To discuss this change it is necessary to understand the nature of gravity, and the relations of ether and caloric. A comet may be nothing more than a body of vapor; but let us take for example such a one as has a solid body for a nucleus.

Now we know, that as any body, whether it be a planet or a comet, approaches the Sun, its own gravitation to the Sun increases; but the gravitation to it of bodies on its surface is diminished. The atmosphere of a comet or any object floating in its atmosphere, for example, is attracted more strongly by the comet as it recedes from the Sun, and the attraction is diminished as the comet approaches. Hence from what I have already said on the relations of ether and caloric in explaining the subject of gravity, we must infer that the caloric atmosphere of the comet has a tendency to become denser as it recedes from the Sun, and to become rarer as it comes nearer to that body. For the Sun diminishes the attraction of the comet for its atmosphere or for objects floating in its atmosphere by exerting an influence in rarefying the caloric around the comet. Hence the comet has a tendency to absorb positive electricity and to discharge negative electricity as it recedes from the Sun; but as it approaches the Sun, it has a tendency to part with caloric or positive electricity. In other words, as the comet approaches the Sun, it becomes more and more positive,—its potential is raised.

Now negative electricity or ether, on account of its extreme rarity, passes without resistance; but the atmosphere of the comet may be supposed to be of a gaseous nature, and, like the aerial atmosphere of the Earth, a non-conductor of positive electricity. We may further suppose, that the comet's atmosphere, like the Earth's, improves in conductivity as its temperature is raised. Now the comet approaches the Sun, carrying with it positive electricity, and its potential grows up more and more as it approaches; until finally bursting through or overcoming the resistance of the non-conducting atmosphere, the electric fluid carries the atmosphere with it, into the regions of space opposite the Sun, which are negative. It first flies out into the

direction of the Sun, because this side of the comet's atmosphere is heated and rendered a better conductor than the opposite side; but it no sooner has escaped to the outside of the comet's atmosphere and beyond its resistance, than its path is changed into the direction opposite the Sun and takes the form of a hollow cone as it is turned back over the comet. This constitutes the comet's tail.

The motion of the Sun around the center of the Universe or of some smaller system, may produce effects like those ascribed to the motion of the planets and comets around the Sun. It may render him magnetic by generating electric currents in his surface, and it may render him luminous by generating electric currents in the upper regions of his atmosphere. Thus it may be supposed, that the Sun's motion and gravity to the center of the Universe is the fuel, which feeds his fires, and this fuel will continue to burn without diminution, until the planets shall all have sunk into the Sun and become extinct, and finally the Sun himself shall sink into the center of the Universe and become a motionless mass, unless regenerated into new life by the quickening power of the Almighty.

There is a hypothesis which explains the origin of the heat and light which we receive from the Sun, as due to the same cause as the interior heat of the Earth. It is supposed, that the entire solar system once existed in a single mass, and that by virtue of intense heat this mass was in the condition of vapor. For matter contains more heat in the state of vapor, than in the liquid state, and more in the liquid, than in the solid. In passing, therefore, from the first state to the last, it throws off heat. It is supposed that by the contraction of the mass above mentioned, the planets were separated one by one in the order of their distance at the present time from the Sun, first Neptune, then Uranus, and last Mercury. As the original mass contracted, its motion

was quickened and gave to each new planet as it sprang from the original a greater velocity in its orbit, than the one which preceded it. The planets in turn undergo a contraction like that of the original mass. Finally they pass from the state of vapor to a state of liquid, and from liquid into solid masses, solidifying first at their surfaces, and at the same time they evolve an enormous amount of heat. This is known as the nebular hypothesis. It both presents us with an account of the origin of the Universe, too beautiful not to be true, and it is one attempt to explain the source of the Sun's heat as well as the interior heat of the Earth.

If this hypothesis be extended so as to apply to the whole Universe, to explain its separation into starry clusters and solar systems and the motions of all these among themselves, some around others and all around a common center, it may be asked, what became of the enormous amount of heat, which was set free, when the original mass of vapor was cooled down? It is plain, that we cannot answer this question upon the assumption, that heat is purely force or the motion of atoms and molecules, if we hold to the doctrine of conservation. For if the heat of the Universe were sufficient at any time to support it in the state of vapor, and the conservation doctrine hold true, it would be sufficient to support it in a state of vapor for all time. For although we may say, that the heat, which sustained the solar system in a state of vapor, passed off into space, meaning thereby the matter, which occupies the space of the Universe, yet we could not affirm, that the heat, which sustained the Universe in a state of vapor, had passed off into space, without admitting, that it is entirely lost or annihilated. For matter and force are inseparable. It appears to me, therefore, that the nebular hypothesis is irreconcilable with that view of heat, which altogether excludes a material theory and makes it consist entirely in motion. It may be said, that heat is con-

verted into other forces. But into what other force could such a vast amount of heat be converted? But if we take the view, which I have explained upon the basis of the double-ether hypothesis, that heat consists not of force only but also of fluid, we may reconcile the nebular hypothesis with the principle of conservation by the assumption, that the heat evolved during the contraction of the nebular masses consists of fluid heat, and that the cooling process consists in the separation of this fluid from the ponderable matter which composes those masses.

There is another hypothesis of the source of the Sun's heat and light, which ascribes it to the incessant impact of falling bodies, which are drawn to the Sun by the force of gravity and the resistance of the interstellar medium. The occasional fall of a meteoric stone to the Earth and the shortening of the periods of the comets are phenomena, which appear to give some support to this hypothesis and have caused it to attract considerable attention.

There are facts, however, which do not sustain either of these two last-mentioned hypotheses concerning the source of solar heat, but seem to indicate that the heat and light of the Sun are related to the causes of the Earth's magnetism and are due to electric currents in his atmosphere. The magnetic needle has been observed to be affected apparently by the occurrence and disappearance of the Sun's spots. Moreover, the most brilliant part of the Sun's luminous atmosphere, like the aurora in the Earth's atmosphere, is in the neighborhood of his poles. Whereas we should think that the impact of meteors should take place chiefly about his equatorial regions; and we should think that the solid part of the Sun would be rendered thus far hotter than his atmosphere; and if hotter, more luminous. For we know, that flame owes its luminosity to the heated solid particles, which it contains, and that the solid particles are rendered

luminous at a much lower temperature, than the gas. The nebular hypothesis, therefore, and the impact theory of meteors do not explain these phenomena of the Sun's luminosity in conformity with our ideas of illumination, according to which solid substances produce a more brilliant incandescence, than those in the form of gas, except in the passage of electricity through attenuated air, when no combustion takes place. Analogy would thus lead us to conclude, that the Sun's heat is generated in his atmosphere and not upon his solid crust; and that the cause is related to the cause, which produces the aurora borealis, the luminous clouds of Jupiter and the brilliant light of comets, as well as the magnetism of the Earth.

Thus gravity, heat and electricity appear to be co-extensive forces, residing in all space and exerted upon matter through the agency of two ethers. When the gravitating force is resisted by the motion of the heavenly bodies, the equilibrium of the fluids is destroyed and electricity is excited; and electric currents thus produced are the source of heat and light.

THE END.